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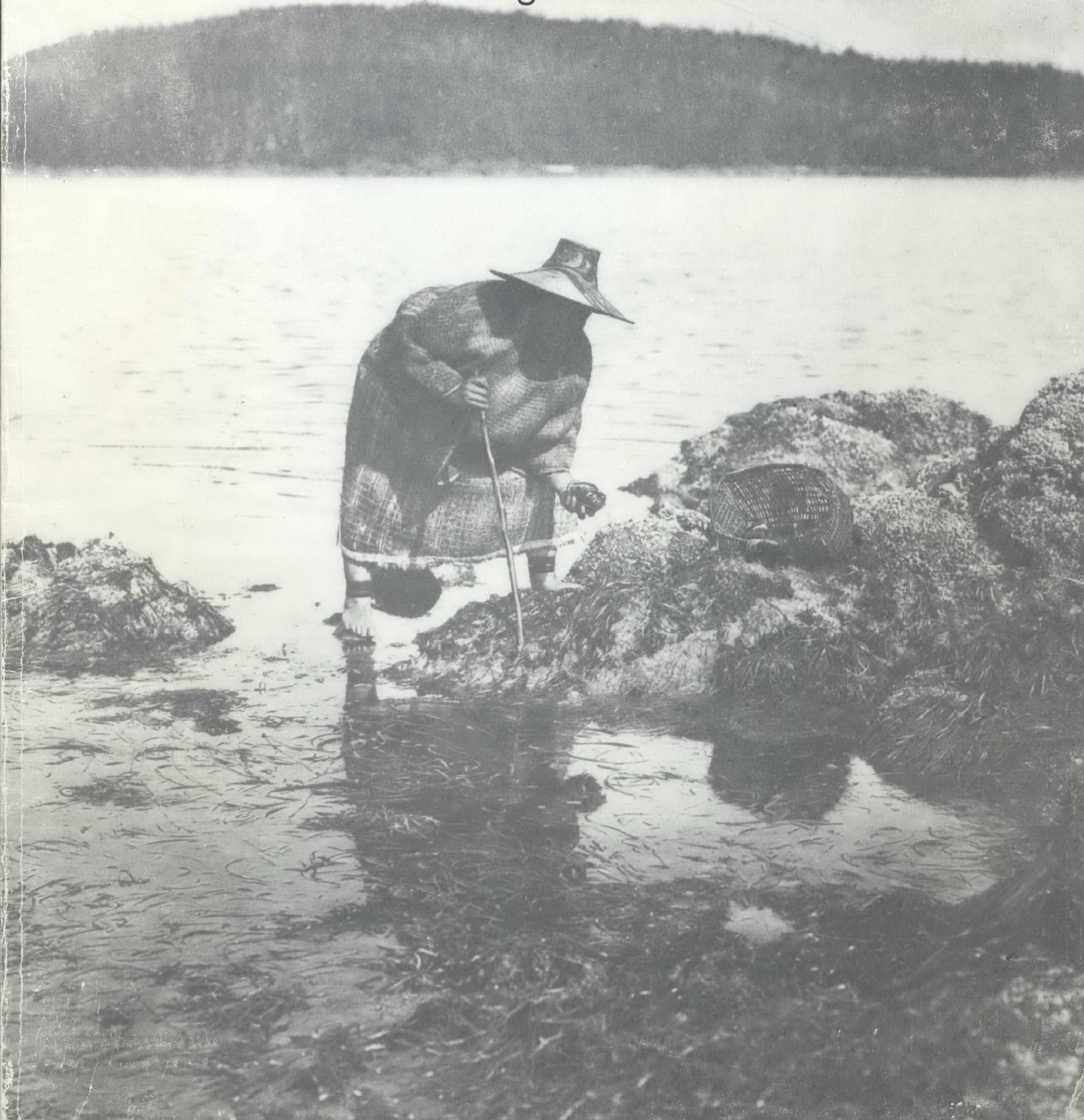
Seagrass Science and Policy in the Pacific Northwest:

Proceedings of a Seminar Series



Front Cover Photo

Gathering Abalone (c. 1914) by Edward S. Curtis.

A black and white photograph of Jessie Sye, a Hesquiat woman, harvesting abalone. She belongs to the Nootka (Nuu-Cha-Nulth) group (Figure 1, Chapter II). On Close examination, *Phyllospadix* spp., surfgrass, rises from the tide pool in the foreground. Plants are also growing just above the water line on the surrounding rocks. The photograph is part of a special collection detailing the activities of Pacific Northwest Natives (NAI folio V. 10, pl 342) and housed at the Special Collections and Preservation Division of Allen Library, University of Washington, Seattle, Washington 98195

Curtis, E.S. 1915. The North American Indian. Vol. 10 Johnson Reprint Collections.

Back Cover Photo

Basketry Whalers' Hat; late 18th to early 19th century
(Spruce root, cedar bark and surfgrass)

This Basketry Whaler's Hat was believed to have been collected by Lewis and Clark during their winter stay at the mouth of the Columbia River. Although it was bought from a resident of the Columbia River region, it was, most likely, made by the whaling people of the coast of Washington or Vancouver Island, Canada. The warp is split spruce root, the weft is black-dyed cedar bark with an overlay of sun-bleached surfgrass. (Information taken from "*A Time of Gathering*" edited by Robin K. Wright, University of Washington Press, 280 pp.).

Photograph obtained from Peabody Museum, Harvard University, photographed by Hellel Burger. Photo No. N31728. Cat No. 99-12-10/53080.

Seagrass Science and Policy in the Pacific Northwest:
Proceedings of a Seminar Series

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Table of Contents

List of Figures

List of Tables

Preface

This report from the seminar, Seagrass Science and Policy, represents a convergence of science and policy. It is a timely step in a continuum of events necessary for knowledgable long-term management which ensures maintenance of seagrass functions in the Pacific Northwest. Taking the next steps will be critical in determining the extent to which such functions will be sustained.

Pioneering eelgrass research was completed by Dr. Ronald Phillips in the 1960s and '70s. This work provided an excellent basis for expansion of investigations into broader ecosystem functional studies. Such studies, while developed and proposed by individuals and consortiums of scientists, have never been completed. As a result, follow-on research has been sporadic and often specific to single projects. In fact, we are still struggling to complete a scientifically sound eelgrass inventory for Washington State.

In the meantime, permit applications for marinas, dredging, and other port development activities continue. Regulatory agencies are required to continue making decisions regarding the long term fate of seagrasses with limited information. These permit applications inevitably spawn questions: To what extent can seagrass beds be restored? How will seagrass beds be affected? How can we get beyond piecemeal, project-by-project management?

This seminar represents the kind of initiative which can help to focus attention on the important issue of seagrass management in the Pacific Northwest. Seminar results reveal needed actions and at the same time tender technical and managerial challenges. Meeting these challenges will benefit citizens, resource agencies, land managers, and regulators.

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Acknowledgments

This document was prepared by the Interdisciplinary Seagrass Working Group (ISWG), School of Marine Affairs, University of Washington. Members of the ISWG include Marc J. Hershman, Annette M. Olson, and Sandy Wyllie-Echeverria. Financial support was received from the U.S. Environmental Protection Agency, Region 10. Fred Weinmann provided suggestions that helped us frame our ideas. We gratefully acknowledge review comments by Andrea Copping. The ethnobotanical information, presented in *Seagrasses of the Northeast Pacific*, this volume, was gathered under a grant from the Hardman Foundation, and Mr. Malcolm Rea. We also acknowledge Peggy Stafford and Marcus Duke for their editorial and production assistance, as well as the staff of the School of Marine Affairs whose editorial assistance is much appreciated. Sandra Kroupa, Book Arts Librarian, was very helpful in obtaining the cover photograph. The students of SMA 550Z, Seagrass Science and Policy Seminar, supplied helpful comments during the course of the seminar. Lastly, the editors especially thank the other contributors to this volume, Charles Simenstad, Mary Ruckelshaus, Doug Bulthuis, Tom Mumford, Kurt Fresh and Ron Thom for their work and effort to provide not only informative and provocative lectures during the seminar, but also to craft their remarks into cohesive summaries for this volume.

INTRODUCTION

Seagrasses are a vital, living marine resource whose presence is critical in nearshore food web dynamics. As such, they have been a focus of scientific inquiry and natural resource management in many coastal states for several decades. In the Pacific Northwest (PNW), natural scientists have investigated seagrass ecosystems since the mid 1960's. Their results, coupled with research from other regions, led to the formulation of seagrass management policies. These policies are formulated to address human activity that might impact seagrasses. If impacts on seagrasses are expected, projects or activities (e.g. dock construction or expansion, dredging and filling) may be modified or abandoned, or some kind of habitat replacement required.

There has also been an effort to quantify the amount of seagrass habitat. Although much of this work has centered on *Zostera marina* L., eelgrass, and to a lesser degree on *Zostera japonica*, some information exists on the other species. However, it is important to note that a comprehensive baseline map for all seagrass species in the Pacific Northwest is lacking.

Although an informal seagrass management program (including plans to provide accurate distribution maps) exists at both the state and federal level, to date there has not been a comprehensive policy analysis to determine the effectiveness of this program. Natural resource managers are left wondering whether current policy is working effectively to protect, conserve and map seagrasses in the Pacific Northwest.

Recognizing that the School of Marine Affairs (SMA), University of Washington could provide a forum to address this question, the Interdisciplinary Seagrass Working Group (ISWG) was formed in the fall of 1992. Our goal was to examine current seagrass management programs in the PNW, using an interdisciplinary approach. As a first step in this process, we offered a *Special Seminar Series,* "Seagrass Science and Policy" (SMA 550Z), during Spring Quarter, 1993. The seminar met weekly for discussions with some of the key figures in seagrass science and policy in the PNW.

The academic program at SMA is designed, in part, to prepare students to face the challenges of careers in coastal zone management. A goal of the *Special Seminar Series* was to acquaint students with current science and policy issues relative to coastal zone management. Accordingly, the seminar was structured to explore seagrass management questions as a microcosm of more broadly based management concerns. Thus, the objectives of the weekly sessions were to: 1) describe, in some detail, the biology and ecology of seagrass resources in the PNW; 2) delineate the types of human activity that were threatening to these resources; 3) define current management strategies to offset these threats; and 4) suggest ways in which seagrass management might be more efficient and effective. Consequently, invitations were extended to speakers who had helped shape the current seagrass management policies and programs in the PNW. We asked speakers to concentrate on two questions:

- Are seagrass resources unique or different in this region?
- Is management history or authority that affect seagrasses unique or different in the PNW?

A second goal was to involve a broader audience in ongoing seagrass science and policy discussions with the ISWG. This volume, summarizing the seminar speakers' remarks will be used to reach a wider audience. The first chapter, Seagrasses of the Northeast Pacific, by Sandy Wyllie Echeverria and Ronald C. Phillips, places PNW seagrass science and policy in a broader historical and geographical framework. The remaining chapters are ordered under the headings of Scientific Issues, Management Issues, and Frameworks for Analysis of the Issues.

Under Scientific Issues are contributions by Charles A. Simenstad, Mary H. Ruckelshaus and Douglas A. Bulthuis (chs. 2-4). Simenstad describes faunal assemblages associated with seagrass communities. He highlights the role of seagrasses in providing "vertical structure" in the water column for shelter, substrate and food. A more comprehensive understanding of basic seagrass biology is offered as the major hurdle confronting effective management. Ruckelshaus reports the current understanding of genetic variation in seagrasses and its relevance to restoration. The challenge for management, she argues, is to resolve which biological/ecological criteria are important to ensure seagrass persistence. Bulthuis sets the issue of light management, regarding Pacific Northwest seagrasses, in a global context. He presents a summary of the factors inhibiting available light and advocates the development of "... meaningful criteria for water clarity ...."

The section on Management Issues presents the contributions of Thomas F. Mumford, Kurt L. Fresh and Ronald M. Thom (chs. 5-7). Mumford provides a summary of seagrass inventory techniques and their possible application in the Pacific Northwest. He urges resource managers to adopt a "business analysis plan" to chart a direction commensurate with goals and funds. Fresh places Washington Department of Fisheries in the context of regional seagrass management programs. He provides a summary of seagrass mitigation projects in Washington state and details a conceptual model used to process a seagrass mitigation project. He advocates augmenting communication with "user/client groups" to "increase the public's confidence in seagrass management." Thom urges the use of concepts from the field of landscape ecology in thinking about and planning for seagrass management. He also challenges managers to design transplants capable of withstanding background natural disturbances (e.g. winter storms). Developing and testing transplant technologies are included in his list of challenges to proper seagrass management.

Frameworks for Analysis of the Issues (chs. 8 and 9) includes two papers. Marc J. Hershman and Kent Lind present a framework for analyzing the legal and institutional context for seagrass science and policy development. They provide an overview of seagrass protection and management policies in the PNW and suggest a procedure for designing, implementing and evaluating new seagrass policies. Annette M. Olson and Alton Straub focus on the development of a research agenda for eelgrass science in the PNW, with the goal of identifying research programs that both answer important ecological questions and address the information needs of environmental decision-makers. They present a method for evaluating the scientific knowledge base and suggest ways to link their analyses with those of Hershman and Lind.

The Seagrass Science and Policy Seminar identified several key issues for seagrass managers in the Pacific Northwest, including

- the potential for non-point source impacts on the quantity and quality of habitat suitable for persistence of seagrasses;
- the need for resource inventories documenting seagrass distributions and characterizing populations;
- the need for restoration of seagrass systems destroyed by coastal zone development;
- enhanced coordination of regulatory and management activities;
- ethnobotanical information and its relevance to policy decisions;
- comparative studies with seagrass systems and policy agendas and activities in other regions of the U.S.; and
- the need for linking management research with basic ecological research.

We have designed this publication to inform regional seagrass management. Each chapter addresses areas of concern and suggests new directions necessary to implement policies and programs that protect and conserve seagrasses. We hope to stimulate and contribute to a regional dialogue on these issues. Additionally, we confirm that the issues identified in the *Special Seminar Series* will be the focus of further study and recommendations by the Interdisciplinary Seagrass Working Group.

1. Seagrasses of the Northeast Pacific

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Seagrasses are a unique suite of plants that inhabit the margins between land and sea (Phillips and Menez 1988). There are 12 genera with approximately 50 species (den Hartog 1970; Phillips and Menez 1988). As distinct from marine algae, seagrasses are rooted in the sediment or rocky crevices and produce seeds (Arber 1920) (Table 1). They occur in tropical, temperate and subarctic coastal waters throughout the world (den Hartog 1970; Phillips and Menez 1988).

In the Northeast Pacific, the seagrass flora includes six species in two genera in the family Potamogetonaceae (Table 2). The distribution of all species is graphically displayed in Figure 1. The most cosmopolitan species, *Zostera marina* (eelgrass), and its role in coastal food webs, is the primary focus of both science and policy in this region (Phillips 1984). The recently introduced plant (1930's and early 1940's), *Z. japonica* (Harrison and Bigley 1982) is beginning to warrant attention from both seagrass scientists and natural resource managers (see Simenstad and Fresh, this volume). However, the three species of *Phyllospadix* (surfgrass), have received little attention, and *Z. asiatica* was only recently described (Phillips and Wyllie- Echeverria 1990). Five of the six species found in the Northeast Pacific occur along the rocky shores and soft-bottom habitats of the Pacific Northwest (Fig.1).

Table I

Adaptations of vascular plants for life in the sea

1. Adapted to life in a saline medium.
2. Able to grow completely submerged.
3. An anchoring system able to withstand wave action and tidal currents.
4. The capacity for hydrophilous (by the agency of water) pollination.

Arber (1920)

Historically, Pacific Northwest coastal natives[1] had many uses for eelgrass (Boas 1921, Kuhnlein and Turner 1991; Turner *in prep*). Most notable were uses by the Kwakwaka'wakw (formerly Kwakiutl) and Haida people (Kuhnlein and Turner 1991). The Kwakwaka'wakw had an elaborate technique for gathering and eating eelgrass. They fashioned "eelgrass twisting sticks", and, from a boat, harvested the plants by twisting the leaves around the "sticks" and pulling the plants from the mud (Boas 1921; Kuhnlein and Turner 1991). The uncooked, washed rhizomes, from a bundle of four plants, were eaten after being dipped in fish oil. It was believed that this dish was the "food of their first mythical people" (Boas 1921; Kuhnlein and Turner 1991). The Haida concocted a tonic for uterine

[1] The location of the Pacific Northwest native groups mentioned in this section can be found in Fig.1.

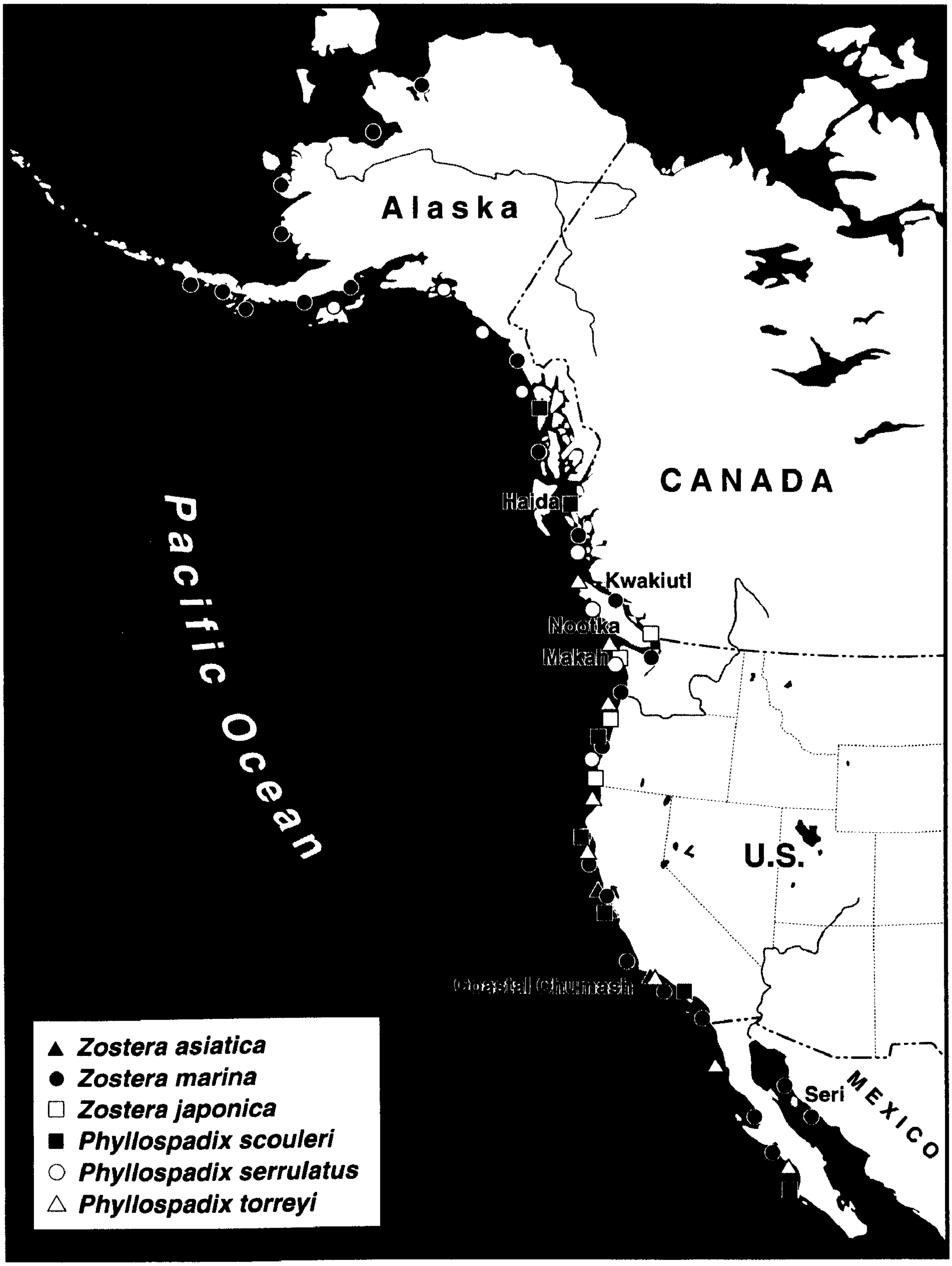

Figure 1. **Distribution of Northeast Pacific seagrasses** (after Phillips and Menez 1988). The symbols depict the overall range for each species. Although the symbols may coincide with actual seagrass locations, this is an artifact of placing them on the coastline. Notice that 5 of the 6 species inhabit the tidal flats and rocky shores of the Pacific Northwest. The coastal native peoples, mentioned in the text, are also referenced (after Northwest Coast volume of the Handbook of North American Indians, Suttles, ed.)

or stomach problems with "four eelgrass roots (probably rhizomes), each from a different tidepool on the side towards the sunrise" (Turner *in prep*).

The Makah used surfgrass (*P. torreyi*) for decorative relief in basketry (Gill 1982). They were also known to eat the rhizomes of several plants (*P. torreyi, P. scouleri,* and, quite possibly, *Z.marina*) (Swan 1870, Gunther 1945; Gill 1982). Most interestingly, the Coastal Chumash (Santa Barbara, California region) fashioned seagrass skirts (*P. torreyi*) (Timbrook and Hoover n.d.). Samples of seagrass thatch from this region have been dated to 1860 ±340 bp (Timbrook and Hoover n.d.; Orr 1968).

Table 2

Classification of Northeast Pacific seagrasses

DIVISION: Anthophyta
  CLASS: Monocotyledoneae
    ORDER: Helobiae
      FAMILY: Potamogen\tonaceae
        GENUS: *Zostera*
          SUBGENUS: *Zostera*
            Zostera asiatica
            Zostera marina
          SUBGENUS: *Zosterella*
            Zostera japonica
        GENUS: *Phyllospadix*
            Phyllospadix scouleri
            Phyllospadix serrulatus
            Phyllospadix torreyi

Phillips and Menez (1988)

In the early part of this century, W.A. Setchell pioneered an eelgrass research project from the Department of Botany, University of California, Berkeley. Setchell assembled a network of scientists, on both coasts, from whom he received both plant data and water and air temperatures (Setchell 1922; 1927; 1929). These collections took place over several years and with these data he was able to provide a comprehensive and detailed description of the morphological and phenological status of *Zostera marina* (Setchell 1929).

Later, and as a response to the effects of the "wasting disease" (loss of eelgrass) and impacts to several species of waterfowl, most especially the sea goose or black brant *(Branta bernicla),* careful and explicit observations by several U.S. Fish and Wildlife biologists were undertaken (Moffitt and Cottam 1941, Einarsen 1965). Most notable was the work of Clarence Cottam and James Moffitt. Cottam and Moffitt, in the mold of Setchell, assembled reports from natural scientists, game wardens, oystermen, interested citizens and U.S. Fish and Wildlife personnel to describe eelgrass abundance at several sites along the Pacific Coast (Moffitt and Cottam 1941). This qualitative "eelgrass census" was updated in 1954 (Cottam and Munro 1954). These observations represent the only biological/ ecological inquiries, relative to Northeast Pacific eelgrass, between the investigations of Setchell, which ended in 1929, and the more "modern" inquiries beginning in the early 1960's (Fig. 2). U.S. Fish and Wildlife continues to monitor eelgrass at several West Coast sites (e.g. Ward and Stehn 1989). The "modern"

Table 3

Major functions of seagrasses

1. Stabilize bottom sediments
2. Slow and retard current, promot ing sedimentation and inhibiting resuspension of organic and inor ganic matter
3. Shelter and substrate
4. Direct (grazing) and indirect (detritus) feeding pathways
5. High production and growth
6. Internalized nutrient cycles

Wood, Odum and Zieman (1969)

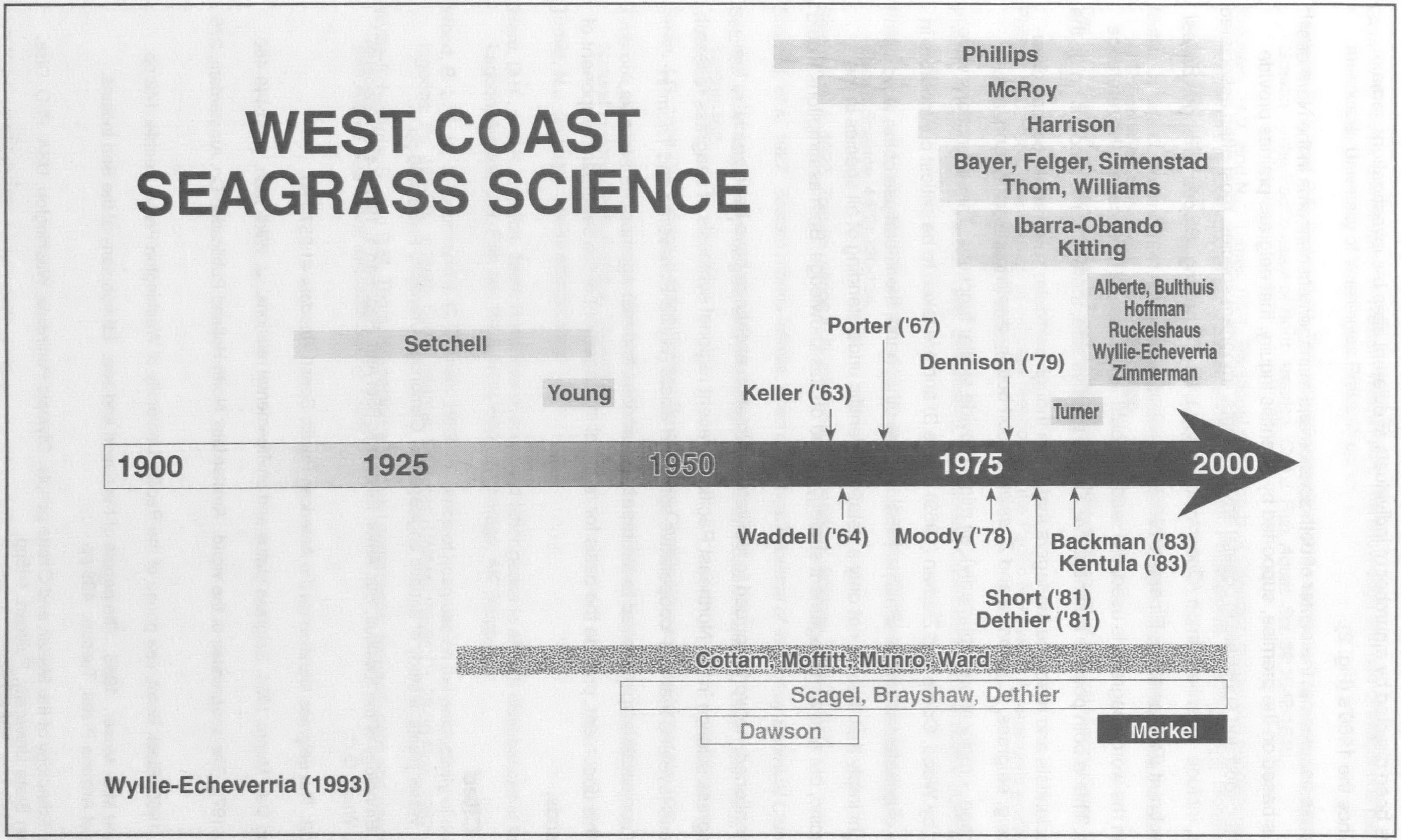

Figure 2. **Timeline depicting seagrass science along the West Coast of North America.** The bars above the arrow, in most cases, refer to research conducted at various west coast universities. Below the arrow, in descending order, the bars refer to: 1) USFW research scientists; 2) marine ecologists noting seagrasses in their published works and 3) E.Yale Dawson, a noted phycologist who had an untimely death as a result of a diving accident and Keith Merkel, an environmental consultant who has developed west coast seagrass transplanting techniques. The names referenced by dates refer to graduate degrees that contributed to an understanding of west coast seagrasses. These scientists, in some cases, pursued seagrass investigations in other regions.

inquiries have been directed by a number of individuals at different sites but investigations remain continuous since the 1960's (Fig. 2).

Eelgrass has been at the center of both science and management concerns in the Northeast Pacific. This is based on the premise, supported by scientific inquiry, that eelgrass prairies provide valuable shelter, food and substrate in coastal environments. Important species, most often associated with eelgrass, include juvenile salmon *(Oncorhynchus* spp.), Pacific herring (*Clupea harengus pallasi* sp.) and black brant (Phillips 1984; Einarsen 1965).

When the word seagrass is used, the reader should know that, in most cases, the reference is to eelgrass. This is both positive and negative. On the positive side, there is some recognition on the part of both scientists and resource managers that, even though particular seagrasses occupy different habitats (e.g. eelgrass, *Z. japonica* and *Z. asiatica* - soft bottom dwelling, primarily, and *Phyllospadix* spp. - rocky shores, primarily), all might provide similar functions. These functions were first identified by Wood, Odum and Zieman (1969) (Table 3) and are taken to be critical contributors in the dynamics of coastal food webs (Phillips 1984). On the other hand, the liberal use of the word seagrass might imply that there is not only a detailed scientific understanding of all species in the Northeast Pacific, but also a management strategy based on this knowledge. Both assumptions would be false.

As mentioned, networks formed to facilitate information exchange have been crucial in the history of seagrass science in the Northeast Pacific. A recent regional synthesis of seagrass research gaps and needs revealed that this "cooperative spirit" still exists (Wyllie-Echeverria and Thom *in press*). This "cooperative spirit" linked to the research priorities and management frameworks, described in this document, provide the basis for regional management of the seagrass component of submerged lands.

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SCIENTIFIC ISSUES

2. Faunal Associations and Ecological Interactions in Seagrass Communities of the Pacific Northwest Coast[1]

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Seagrass communities likely rank with marine kelp (macroalgae) systems as the marine analog to tropical rain forests in structural complexity, biodiversity, and productivity. In many aspects, they easily exceed the touted terrestrial ecosystems. By their position at the land-ocean margin, seagrass communities are also an integral element in the continuum of material and organismal transport along the estuarine environmental gradient. That gradient is a conduit for sediments, organic matter, nutrients and biota that cross the land margin, often in both directions. At the polyhaline transition in estuaries, seagrass habitats are situated at the "node" of material transformation and biotic transition. Undoubtedly, the best known biota passing through estuarine seagrass habitats are juvenile anadromous fishes such as Pacific salmon (*Oncorhynchus* spp.), but many other important ecological, physical, and geochemical processes are concentrated within seagrass habitats.

This paper is a synopsis of one aspect of these seagrass community processes, e.g., that of ecological linkages involving biota directly or indirectly dependent upon seagrasses. I will primarily address two aspects of seagrass communities: (1) assemblages of organisms that are discretely associated with seagrass habitats, and their interaction within the habitat; and (2) linkages between the community and the (estuarine) ecosystem within which it is set. This perspective will emphasize trophic-dynamics aspects (*sensu* Lindeman 1942) of the seagrass communities, not only because that has been the research focus of myself and my colleagues, but also because I believe that many of the more important ecological functions (e.g., "services"[2]) provided our society and economy are

1 With apologies to the seminar series organizers, I choose to call the seagrass habitat and its associated flora and fauna "communities" based on definitions such as Menge and Sutherland's (1976) "an association of interacting population of all trophic levels occurring in a given habitat;" my view of "ecosystem" is more holistic, encompassing both the biotic components (communities) and abiotic environment with which they interact. Thus, at a minimum, seagrass communities exist within coastal or estuarine ecosystems and may actually be incorporated into the whole land-ocean ecosystem, from watershed to open ocean.

2 I distinguish "ecological functions" from "ecological processes" in this case. Of the multitude of ecological processes that are occurring in any ecosystem, ecological functions are restricted to those to which we as a society and culture have attached particular importance; "ecological values" would be a subset of the functions, i.e., those that have a particular economic value attached. Ecological processes are universal and relatively consistent, but ecological functions and values waft variably as a function of social and cultural (and political!) trends. Thus, parasitism will always be with us as an ecological process, but seldom recognized as an ecological function, as would mountain lions feeding on deer or elk, which in turn is considered a worthwhile function by many segments of our society irrespective of its marginal economic value.

accounted for by trophic linkages. Although my focus will be on consumer assemblages and their ecology in *Zostera marina,* eelgrass, communities along the northeastern Pacific Northwest coast, I will try to incorporate some evidence from *Z. marina* communities in other regions and will also mention the introduced species, *Zostera japonica*, that has become established in certain estuaries in this region.

State of Our Understanding

Wood et al. (1969) and Zieman (1982) describe six major functions of seagrasses (Table 3, ch. 1). Of these, shelter and substrate, direct and indirect feeding pathways, and current mediation are the most directly responsible for the composition, diversity, production, and trophic interactions of seagrass consumer organisms. Kikuchi and Pérès (1977) and Kikuchi (1980) also cite maintenance of high dissolved oxygen and the mitigating effect of shading on water temperatures and salinities as additional factors under the function of shelter and substrate.

Consumer organisms are both resident and transient members of seagrass communities. Although some organisms appear in seagrass habitats in no greater incidence than any other habitat, most occupy the habitat "preferentially"[3] over other, predominantly unvegetated habitats. The ecological, and inherently evolutionary, processes that account for both resident and transient consumer use of seagrasses relate to increased fitness, e.g., promoting some increased chance for survival to reproduction. In seagrasses, processes that *directly* increase fitness could include, but are not necessarily restricted to (1) unique or enhanced reproduction; (2) optimum foraging that results in significantly higher growth rates; (3) refuge from predation resulting in increased survival; and (4) optimization of physiological conditions affecting both growth and survival.

Consumer reproduction in seagrasses is usually associated with plant substrates, either the seagrass itself or macroalgae that are associated with the community. The best, and most valuable, example in this region is the importance of many eelgrass sites as Pacific herring (*Clupea harengus pallasi)* spawning sites (Phillips 1984: Simenstad 1987). Not all seagrass habitats are herring spawning sites. We still have no definitive information that explains why certain sites are important and others are not; we must assume at this stage that either unknown characteristics of these habitats are unique or that the setting of these sites in the larger scale of estuarine and coastal circulation or other factors has dictated their importance over evolutionary time.

Optimal foraging implies prey resources that are uniquely or abundantly associated with seagrass habitats or increased prey capture rates, such that consumers can gain maximal assimilation of prey biomass when feeding within the habitat. Although direct herbivory in other, especially tropical, seagrass communities is more common, there are relatively few herbivores on *Zostera*

[3] I use this term somewhat loosely, suggesting that there is a volitional behavior toward occupying the habitat preferentially over other, adjacent habitats but acknowledging that there have been no specific studies, to my knowledge, that have actually documented "preference" *per se*; rather, most studies have just shown higher abundances (or rarely, exclusive occurrences) in seagrasses than in adjacent habitats

marina and *Z. japonica* in the Pacific Northwest. Notable exceptions include several species of waterfowl such as brant (*Branta bernicla*), Canada geese (*B. canadensis*), wigeon (*Anas americana*), gadwall (*A. strepera*), and pintail (*A. acuta*) ducks (Phillips 1984). Isopods (*Idotea* spp.) may also constitute another important herbivore, but we are still uncertain how much of their production derives from epiphytes versus the eelgrass. Therefore, most trophic linkages in seagrass communities are at the secondary or higher consumer levels, i.e. predators feeding on herbivores or detritivores. A good example of this is the abundance and availability of certain prey that are attached to eelgrass, for instance the caprellid amphipods that shiner perch (*Cymatogaster aggregata*) feed upon extensively (Caine 1980). As an example closer to this region, we have found in our studies of eelgrass communities in Padilla Bay (Simenstad el at. 1988) that specific taxa of harpacticoid copepods (e.g., *Harpacticus uniremis*[4], *Zaus* spp.), which are essentially unique to the eelgrass epiphyte assemblage, are the principal prey items of juvenile chum salmon (*Oncorhynchus keta*), Pacific herring, Pacific sand lance (*Ammodytes hexapterus*) and surf smelt (*Hypomesus pretiosus*). All these fishes are of either commercial or ecological (i.e. as prey of economically important species) value in the Pacific Northwest.

Refuge from predation is a function of the structural complexity of seagrass habitats, which is superior to all but kelp forests among estuarine and nearshore marine communities, and in terms of microhabitats, may also exceed kelp forests. The structural complexity of the seagrass and associated macro- and microalgae, bryzoans, hydroids, and other epifauna and epiflora inhibits the success rate of predators that are unwilling or ineffective feeders within the habitat as compared in unvegetated or less vegetated communities. Although rarely tested, this is likely the primary explanation for the predominance of juvenile fishes (numerically, if not gravimetrically) in the fish assemblages of seagrass communities in the Pacific Northwest (e.g. Miller et al. 1980) and other comparable regions (Heck and Orth 1980; Orth and Heck 1980). Heck and Thoman (1981) provide one of the few explicit indications that predation rates (on grass shrimp, Palaemonetes pugio, by killifish, *Fundulus hereroclitus*) are mediated by seagrass (turtlegrass, *Thalassia testudinum*).

Physiological mechanisms for seagrass habitat use by consumers are more speculative. Habitat use is assumed to be tied to the maintenance of lower and narrow ranges of temperature and, at least during daytime, higher concentrations of dissolved oxygen (Phillips 1984). Many organisms also may not be able to tolerate direct light intensities that would otherwise be present in these shallow water habitats without the shading influence of seagrasses.

These four mechanisms for consumer-specific reliance on the seagrass habitat are highly interrelated, however, and no one mechanism is uniquely responsible. For example, at least during their juvenile stages, if not throughout their life history, certain fishes may be highly adapted (morphologically as well as behaviorally) to feed on specific seagrass prey fauna, as they minimize mortality by

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4 Since these studies, we have found *H. uniremis* abundantly associated with other epiphyte or epiphyte-like (e.g., diatom mat) microhabitats in other habitats; but, in many estuaries eelgrass epiphytes are the predominant location for these assemblages.

seeking refuge within the seagrass habitat from predators outside (e.g., Pollard 1984). And, the "optimal" consequences (e.g., energy available for growth and reproduction) of foraging are linked directly to the amount of time and energy these fishes must expend avoiding the predator, as well as the energetic expenditures involved in preying upon organisms with different spatial distributions within and outside the habitat and their avoidance capabilities (Townsend and Winfield 1985). To some degree, water temperatures and dissolved oxygen levels will also influence the amount of energy which can actually be assimilated into somatic or gonadal tissue. Thus, given the aggregate and interrelated evolutionary influences on morphological, behavioral and life history traits of consumers we find characterizing the eelgrass community today, it is impossible to relate their dependence upon the habitat to any one particular attribute of the eelgrass habitat or community. Instead, we must examine particular seagrass functions (e.g., "fish nurseries") as the integrated consequence of the evolution of both seagrasses and estuarine and nearshore marine fauna, i.e., the coevolution of the community constituents. It is also important to remember that seldom, if ever, have scientists empirically established the fitness benefit of consumer organisms' use of seagrass habitats, e.g., in terms of survival to reproduction. At present, we must simply use the descriptive nature of the diverse, complex assemblages of organisms and predator-prey interactions that characterize seagrass communities (Fig.1) as evidence for a highly co-evolved and "interdependent" community.

Challenges to Seagrass Science and Policy

As with any complex ecosystem with which our culture interacts, effective management of seagrass communities demands both a comprehensive understanding of the basic biology of seagrasses (the elemental building block of the habitat) and other biota in the community, and an applied science knowledge of the community's responses to natural and anthropogenic stresses. Compared to analogous communities, terrestrial as well as marine, policy and management decisions involving seagrasses and natural resources that depend upon this community are severely limited by the immature state of basic and applied science. The challenge to increase our understanding of seagrass communities, and their role in estuarine ecosystems, may seem mundane. However, understanding the role of seagrass communities in fundamental ecosystem processes is not a trivial objective, and has generally not been achieved beyond the descriptive or conceptual stage.

Integration of seagrass science and policy in the coming years will require:

(1) assessing the significance of utilization and extended residence in seagrass habitats to the growth and survival of fishes and macroinvertebrates that occupy seagrass as nursery habitats;

(2) determining the relationship between various structural and spatial aspects of seagrass habitats and basic functions such as fish and macroinvertebrate utilization, e.g., variation of fish and macroinvertebrate foraging as a function of plant density and standing stock, blade width, patch size, epiphyte composition and standing stock, etc.;

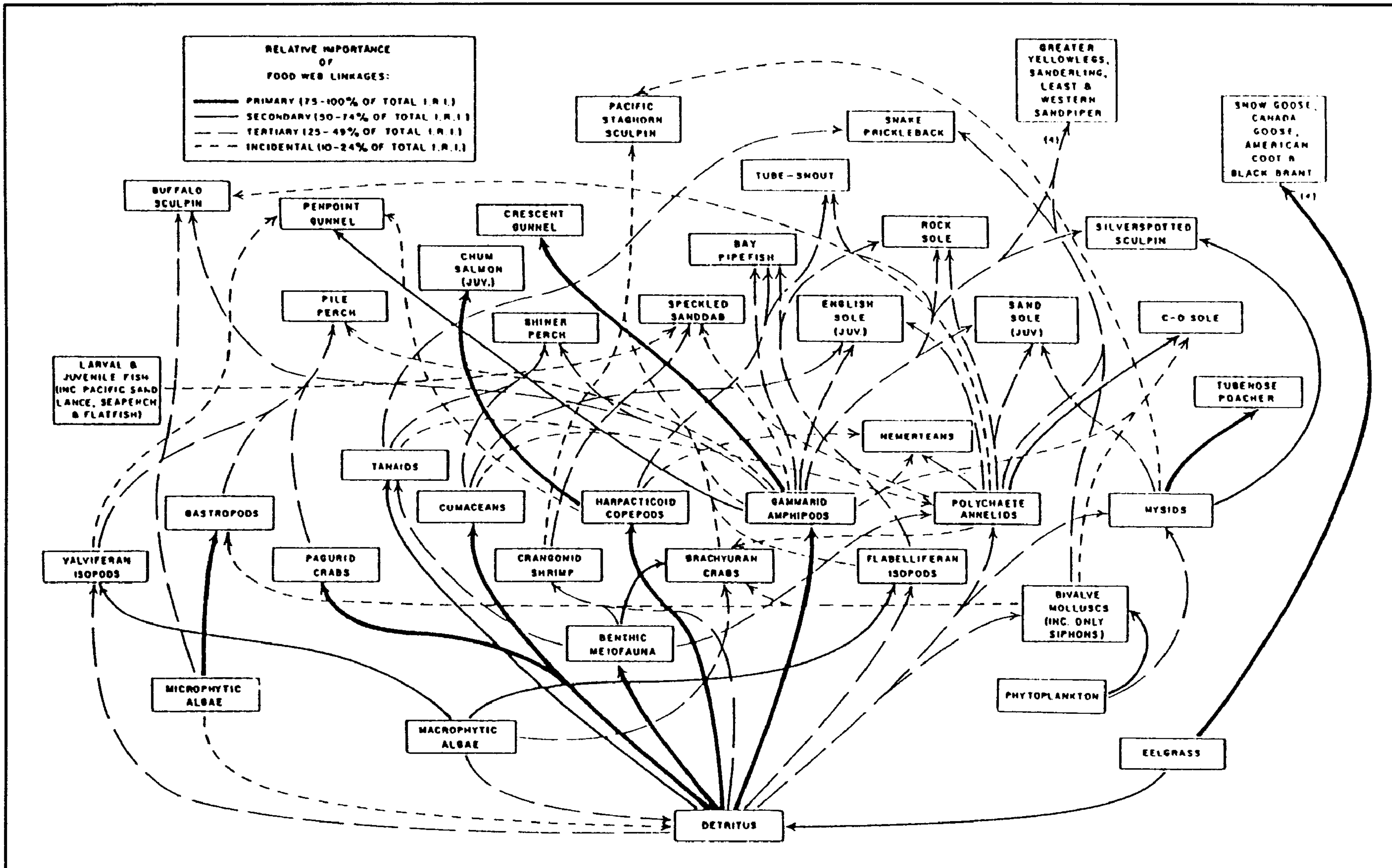

Figure 1. **Composite food web characteristics.** Protected sand/eelgrass, shallow sublittoral habitats in northern Puget Sound and the Strait of Juan de Fuca (from Simenstad et al. 1979).

(3) tracing the contribution of seagrass-generated organic matter to food web path ways beyond the seagrass community, and in particular in the deep subtidal portion of estuaries and inland seas that are the likely depositories of eelgrass detritus (Appendix, page 17);

(4) assessing the influence of seagrass patch structure (e.g., size, configuration, edge, area/ aspect ratio, etc.) on both endogenous and exogenous processes and functions; and,

(5) determining the rate of herbivory specifically on the seagrass, both from macroherbivores (e.g., water fowl) and microherbivores (e.g., isopods).

Conclusions

Much, if not the majority, of direct faunal associations can be tied to the physical structure of seagrasses rather than direct biotic (i.e., as a result of the plants' autotrophic processes) interactions. Perhaps one of the most important attributes of seagrasses, at least with *Zostera marina* in the Pacific Northwest region, is the structural complexity and food resources provided by epiphytes attached to seagrasses. A unique aspect of seagrasses is that they are annually providing new substrate which develops a complex and changing microhabitat of diatoms, macroalgae, bryozoans, hydroids and other flora and fauna. The incredible productivity of the combined eelgrass/epiphyte autotrophic assemblage is not only responsible for a richly complex habitat and secondary production of consumers within the habitat but also for the entrapment of organic matter that can decompose and enter food webs within the habitat. However, perhaps the most important biotic function of eelgrass on the scale of entire estuaries or coastal ecosystems is in exporting organic matter that supports secondary productivity in other habitats through detritus-based food webs (Appendix, page 17). While we have at least qualitatively documented many of the intrahabitat (i.e. "community") relationships, and especially food web structure, we have yet to evaluate the broader (i.e. "ecosystem") importance of seagrass habitats to other communities in the coastal region.

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Appendix: Isotopes and Seagrasses

Indirect contributions to consumers may be difficult to detect, but are potentially more relevant to management than direct feeding because they identify the connections between the seagrass and other communities, perhaps even those that are not immediately adjacent to seagrasses; i.e., they establish the "waterscape" ecology perspective. Some of the more obvious indirect contributions are tied into the role of seagrasses to transient consumers, e.g., spawning sites for Pacific herring in Puget Sound that ultimately, after they have left the seagrass habitats as larger juveniles, provide valuable prey resources for predators in coastal and open ocean ecosystems across the entire North Pacific. Undoubtedly, the largest contribution of seagrasses external to the habitat proper is the production and export of a tremendous amount of organic matter, both particulate and dissolved, and may account for an extensive amount of the nearshore fisheries production (e.g., Barsdate et al. 1974). In that detritivores form most of the intermediary linkages in estuarine and coastal food webs, such as in Puget Sound (Simenstad *et al.* 1979; Fig. 1), seagrass is likely the primary source to these detritus-based food webs. For example, we are accumulating evidence using stable isotopes of carbon as "biomarkers" that the organic matter generated by eelgrass and associated epiphytes are an important, and often dominant, constituent in consumers in estuaries of Puget Sound (Simenstad and Wissmar 1985; Ruckleshaus 1988). In Hood Canal, we found that the $\delta^{13}C$ signature of estuarine consumers were strongly influenced by the ^{13}C-enriched autotrophs in the eelgrass habitat compared to the ^{13}C-depleted organic matter from terrestrial plants or neritic phytoplankton. This "enrichment effect" may have even extended into marine littoral and neritic consumers. In addition to the export of organic matter to food webs in other habitats, it must also be recognized that the physical structure of seagrass habitats also accounts for trapping, and considerable consumption, of organic matter that is transported into the habitat (Phillips 1984).

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3. Incorporating the Population Biology of Eelgrass into Management

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Eelgrass meadows are valuable estuarine and coastal habitats whose possible declines (Thom and Hallum 1990) are prompting scientists and policy makers to reevaluate existing management approaches. Seagrass management to date has focused on mitigation of habitat loss through transplant projects. Transplantation of eelgrass as a restoration tool has had mixed success and, even in cases where transplants survive, the functional equivalence of the restored and natural meadows has not been established (Fonseca et al. 1988). Furthermore, consistent and reliable methods for evaluating the success of restoration projects are not used. Therefore, our ability to evaluate the effectiveness of different techniques is severely limited. By incorporating lessons from research in population biology of natural plant populations, management approaches designed to protect and restore seagrass systems can be greatly improved. In this paper, I discuss how insights from theoretical and empirical research in plant population biology can be used to address challenges facing seagrass scientists and policy makers concerned with preservation of eelgrass systems.

Lessons from Population Biology

The sizes of eelgrass populations in nature are becoming smaller due to human-caused fragmentation of natural beds and because logistical considerations limit the size of restored populations. As population size decreases, stochastic processes (e.g., loss of individuals or alleles, year to year fluctuations in seed production) become more important. In addition, evolutionary theory suggests that in smaller populations, the genetic composition of members has an increased influence on population growth rate and persistence (Barrett and Kohn 1991). There is no empirical information relating changes in eelgrass biology to changes in population size. It remains an important empirical question whether changes in ecological (e.g., pollen and seed dispersal, seed production) or genetic (e.g., mating system, number of alleles) attributes in small populations have a demonstrable effect on eelgrass population growth rates or persistence. Results from such inquiries are critical for effective design of restoration projects.

Independent of population size, the degree of patchiness will also affect a species' persistence. A major contribution from theoretical and empirical work in plant population biology is acknowledgment of the difficulty in defining a "population". In order to study the biotic and abiotic factors regulating population size or growth rate, genetic and ecological criteria must be used in choosing a "biologically relevant" group of interacting individuals. Eelgrass is often patchily distributed at a number of spatial scales (i.e. within and among embayments), and the extent to which water-mediated dispersal creates connections among patches will ultimately determine the number of interacting individuals in a population and their response to perturbation. Reproductive, morphological, and genetic characteristics in eelgrass are spatially patchy throughout its range in the Northeastern Pacific (Fig. 1). Ecological characteristics such as leaf width and the incidence of flower and seed production vary dramatically, even within Pacific Northwest estuaries (Phillips et at. 1983, Backman 1991, Ruckelshaus 1994). In studies of the distribution of genetic variation in eelgrass among and within embayments in Puget Sound, I have found significant differences in the genetic composition among patches within a bay and between bays (Ruckelshaus 1994; Fig.1).

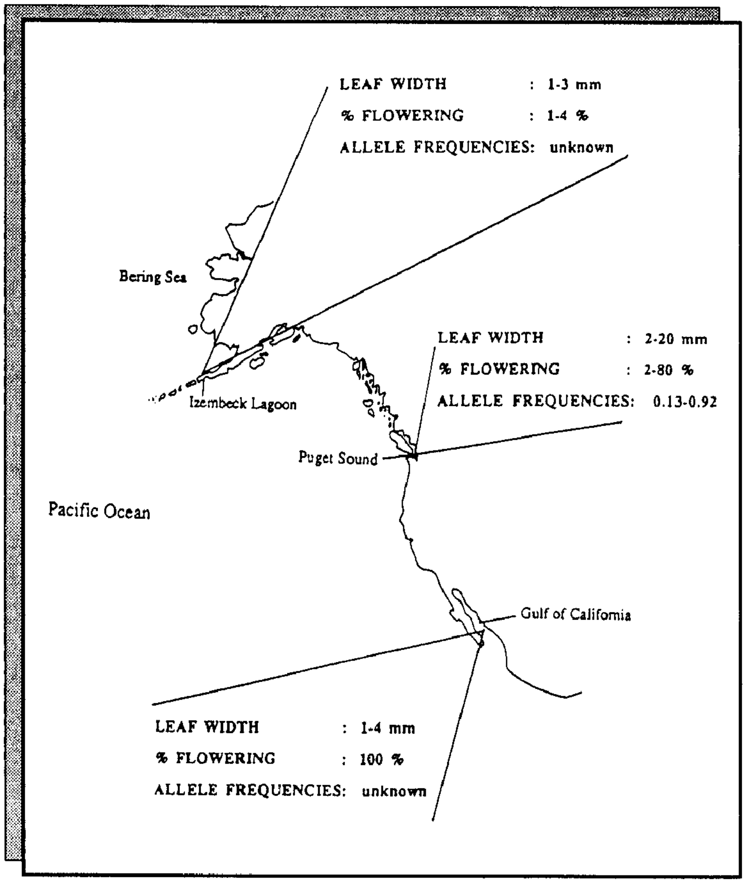

Figure 1. **Ecological and genetic differentiation in eelgrass (*Zostera marina*) populations of the Northeast Pacific.** Leaf width and percent flowering data are from Phillips et al. (1983), Backman (1991), and Ruckelshaus (1994). Allele frequencies represent the range in frequency of the most common allele (mean of five polymorphic loci) among 20 patches in northern Puget Sound (Ruckelshaus, 1994).

For ecological attributes that are genetically based, differentiation among patches may increase their isolation and affect the persistence of eelgrass populations. I found evidence for genetically based ecological differences between habitats in a study in which I transplanted seeds between tide zones within a bay in the San Juan archipelago. Seeds did not germinate well when planted into a “foreign” tide zone as compared to germination rates in their "home" tide zone (Ruckelshaus 1994). This evidence for local adaptation points to the need for attention to both donor and site characteristics when designing eelgrass restoration projects.

Intertidal eelgrass populations are often dynamic, and in many habitats, high rates of patch turnover should be expected to occur under natural conditions. As long as recolonization of suitable habitat keeps pace with disappearance of patches, populations in highly disturbed environments will persist. In eelgrass populations with a high incidence of sexual reproduction, the availability of suitable but unoccupied habitat may limit successful colonization of new populations in the face of local patch extinction. In addition, high rates of patch turnover due to physical and biotic disturbance can overwhelm any effect of ecological and genetic characteristics of patches or their persistence

(Ruckelshaus 1994). Monitoring of eelgrass populations should take into account not only the disappearance of existing patches, but also the rate of occurrence of newly colonized areas.

Challenges Facing Seagrass Scientists and Policy Makers

A major challenge facing scientists concerned with eelgrass habitat protection is to determine which aspects of eelgrass biology are critical to population persistence. Clearly, existing approaches to eelgrass management do not incorporate enough information about ecological and genetic factors affecting population growth. Our research priority should be to find the most parsimonious combination of biological details needed for predicting population growth and survival. For managers whose task includes isolation and prevention of numerous potential causes of eelgrass declines, the simpler the model of factors affecting the health of eelgrass populations, the better. We do not have the luxury in time or resources to fine-tune an eelgrass policy by incorporating extraneous ecological or genetic factors with no demonstrable effects on eelgrass persistence. An explicit demographic analysis of population growth rates and factors limiting life history stage transitions is needed (Schemske et al. *in press*). We can only address this need with rigorous experimentation and documentation of how variation in life history characteristics, morphology and genetic composition of individuals affect the demography of eelgrass populations.

An important gap in eelgrass policy is the lack of attention paid to the effects of natural population and patch dynamics in monitoring designs. The high rates of patch turnover characteristic of many (especially intertidal and disturbed subtidal) habitats necessitate that both existing and available, but unoccupied, patches be censused regularly. In this way, eelgrass habitat can be more appropriately defined as all suitable sites, occupied or not. For inventory purposes and in monitoring the changes in demography of restored and natural populations, a focus on the whole landscape is critical. Finally, because eelgrass populations in the eastern Pacific Ocean have a unique genetic and demographic history as compared to those in the Gulf of Mexico or the Western Atlantic Ocean, policy aimed at protecting Pacific populations of eelgrass should be guided by biological information obtained from those same populations. In addition to the striking physical (e.g., slope of continental shelf, tidal range and periodicity) and biological (e.g., competitors, herbivores, parasites) contrasts between the ocean basins, the Pacific and Atlantic populations have had historically different population size fluctuations. For example, the Atlantic eelgrass populations have experienced a number of documented catastrophic declines over the past century due to a “wasting disease” (Muehlstein 1989). Such periodic bottlenecks in population size result in dramatic changes in genetic composition, none of which have been documented in Pacific populations despite the presence of disease symptoms (Short et al. 1987, Muehlstein et al. 1988).

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4. Light Environments/Implications for Management

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The light requirements of seagrasses are often an overlooked factor in the management of bays and estuaries. In this article I will outline some evidence that (1) seagrasses need light, (2) their lower depth limit is controlled by light, (3) increased suspended sediments and phytoplankton in the water reduce light to seagrasses, (4) increased growth of epiphytes reduces light to seagrasses, and (5) many of the major losses of seagrasses throughout the world have been attributed directly or indirectly to reduced light.

Seagrasses require sufficient light for growth and survival, but seagrasses near the lower depth limit within any estuary or bay are often restricted in their growth and distribution by lack of light. Loss of water clarity reduces the depth penetration of seagrasses, making large areas of subtidal habitat unsuitable for growth. These changes are rarely seen or reported because they occur at the deeper end of the distribution of seagrasses and not in the intertidal where changing distribution patterns are more easily observed. The losses can occur slowly and incrementally. However, their net effect in eliminating seagrass is just as effective as when habitat is dredged, filled or shaded by a nearshore structure.

The lower limit of distribution of seagrasses is often controlled by the amount of light. The importance of light has been demonstrated experimentally (Backman and Barilotti 1976, Bulthuis 1983, Dennison 1987) and in surveys of the lower depth limit of seagrasses. Duarte (1991) has reviewed many surveys of seagrass distribution and measurements of light at the lower depth limits. Based on these surveys, Duarte suggested that about 20% of the surface light is required for survival of *Zostera marina.* Almost all of these surveys were conducted outside the Pacific Coast of North America. However, they represented widespread geographic areas and there was close agreement in the percent light measured at the lower depth limit. Management of *Zostera marina* on the Pacific Coast of North America should focus on ensuring that 20% of incident light reaches the desired lower limit of eelgrass distribution.

The requirement of seagrasses for clear water above them for light transmission makes management more complex. Light transmission in estuaries and bays may be reduced by suspended sediments, phytoplankton, and/or dissolved organic material. The concentration of these materials is dependent on a variety of management activities, including clearing of forested watersheds, dredging in the bays, discharge of municipal wastewater, runoff from agricultural fields, and storm water runoff. Phytoplankton growth and biomass may increase when the supply of nutrients is increased. As nutrient supply increases, phytoplankton biomass may increase, and the increased biomass (usually measured as concentration of chlorophyll) absorbs more of the light before it reaches the seagrasses. Thus, management becomes more complex because so many factors need to be considered and controlled.

Nutrient increases affect epiphytes of eelgrass as well as phytoplankton. When epiphyte growth is stimulated by water borne nutrients, the biomass of epiphytes can shade the eelgrass leaf to which it is attached and reduce the time that a leaf of eelgrass can have positive net photosynthesis (Bulthuis and Woelkerling 1983). The nutrient-epiphyte-eelgrass relationship is further complicated by the interaction between grazers and epiphytes. If grazer density is high enough, epiphyte grazers can keep the biomass of epiphytes low in spite of high nutrient supply (Orth and Van Montfrans 1984, Williams and Ruckelshaus 1993). Understanding the effect of grazers on epiphyte biomass has been important in explaining the survival of eelgrass in some areas where nutrient supply is high and growth of phytoplankton and epiphytes would have been expected to kill the eelgrass through light reduction.

The importance of light to seagrasses is illustrated by major losses of around the world, where reduced water clarity has been identified as a major cause. The loss of most submerged aquatic vegetation from Chesapeake Bay was attributed to the increased suspended sediments and nutrients that reduced water clarity and increased growth of epiphytes (Orth and Moore 1983, Kemp et al. 1983, Dennison et al. 1993). In the Dutch Wadden Sea, huge areas that formerly supported growth of eelgrass are now bare, apparently because suspended sediments made the light climate unsuitable (Giesen et al. 1990). In Western Port, Victoria, Australia, more than two-thirds of the seagrasses declined over a 10 year period, apparently because the suspended sediments settled on the leaves blocking light (Shepherd et al. 1989). In that case, the loss of seagrass resulted in erosion of mud banks leading to increased suspended sediments and further losses of seagrass. Here on the west coast of North America the very limited distribution of seagrass in San Francisco Bay appears to be a result of the low water clarity in the bay (Wyllie-Echeverria 1990, Zimmerman et al. 1991). These examples all indicate the importance of light to seagrass, the vulnerability of seagrass to factors that decrease light, and the need to place greater emphasis on water clarity to protect and enhance seagrass on the west coast of North America.

The light requirements of seagrasses and the many factors included in determining the light climate of the eelgrass leaf (such as suspended sediment, phytoplankton, nutrients, and epiphytes) emphasize the importance of watershed management if eelgrass are to survive. The Chesapeake Bay management committee recognized the integrating role of eelgrass and other submerged aquatic vascular plants as an assessment of water quality in Chesapeake Bay (Fig.1). Efforts to improve water quality in various parts of the estuary will be judged by whether aquatic plants, including eelgrass, survive and become re-established in areas of suitable substrate. The specific water quality criteria developed in Chesapeake Bay may not be helpful on the west coast, but the watershed and

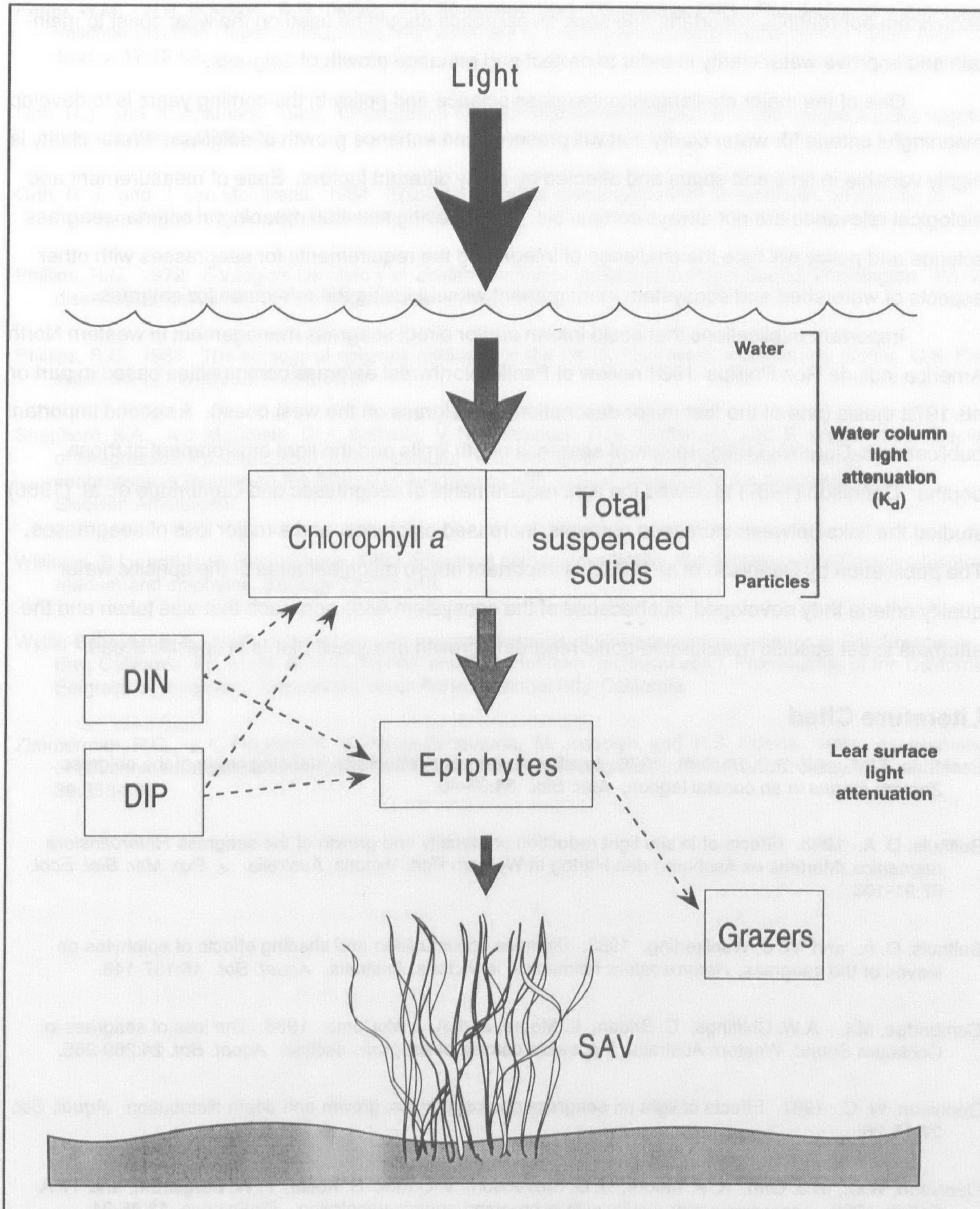

Figure 1. **Dynamics of light attenuation in nearshore seagrass communities** (Dennison et al. 1993). Availability of light for submersed aquatic vegetation (SAV) is determined by light attenuation processes. Water column attenuation, measured as the light attenuation coefficient (K_d), results from absorption and scatter of light by particles in the water (phytoplankton, measured as chlorophyll a, and total organic and inorganic particles, measured as total suspended solids) and by absorption of light be water itself. Leaf surface attentuation, largely due to algal epiphytes growing on submersed leaf surfaces, also contribute to light attenuation. Dissolved inorganic nutrients (DIN, dissolved inorganic nitrogen; DIP, dissolved inorganic phosphorus) contribute to phytoplankton and epiphyte components of overall light attenuation, and epiphyte components of overall light attenuation, and epiphyte grazers control accumulation of epiphytes.

ecosystem approach is important, and such an approach should be used on the west coast to maintain and improve water clarity in order to protect and enhance growth of eelgrass.

One of the major challenges to seagrass science and policy in the coming years is to develop meaningful criteria for water clarity that will preserve and enhance growth of eelgrass. Water clarity is highly variable in time and space and affected by many different factors. Ease of measurement and biological relevance are not always compatible. Once having selected meaningful criteria, seagrass science and policy will face the challenge of integrating the requirements for seagrasses with other aspects of watershed and ecosystem management without losing the relevance for eelgrass.

Important publications that could inform and/or direct seagrass management in western North America include Ron Phillips' 1984 review of Pacific Northwest eelgrass communities based in part on his 1972 thesis (one of the first major descriptions of eelgrass on the west coast). A second important publication is Duarte's (1991) review of seagrass depth limits and the light environment at those depths. Dennison (1987) reviewed the light requirements of seagrasses and Cambridge et. al. (1986) studied the links between increased nutrients, increased epiphytes, and a major loss of seagrasses. The publication by Dennison et al. (1993) is important not so much because of the specific water quality criteria they developed, but because of the ecosystem-wide approach that was taken and the attempts to set specific measurable goals regarding growth of aquatic plants in specific areas.

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MANAGEMENT ISSUES

5. Inventory of Seagrasses: Critical Needs for Biologists and Managers

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"Hard t'say without knowin' "

D. Melvin

An inventory of a natural resource is the elucidation of the type, amount and location of that resource, sometimes done on a one time basis (baseline) or several times to determine changes in the type, location or amount of the resource (trend analysis). An inventory of all the resources in an area is a synoptic inventory, the inventory of only one or a few resources is a thematic inventory. Inventories are critical to good management of natural resources. Without knowledge of what is being managed, policy development and planning are being carried out in the dark. This paper discusses the inventory of *Zostera marina,* eelgrass, and *Zostera japonica* in the Pacific Northwest.

Inventories as Information System

Inventories should be viewed as information systems which create and maintain a spatial data base and deliver useful information to the end users. This means that all activities should be coordinated and planned. These activities are usually performed in this sequence:

A. Business Needs Analysis
B. System Design and Construction
C. Data Acquisition
D. Ground Truthing
E. Data Analysis
F. Data Storage
G. Product Delivery
H. Maintenance
I. Documentation on an ongoing basis

A detailed explanation of these nine points is provided in the Appendix, pages 31-35.

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Historical Inventories

Eelgrass has been inventoried in a variety of methods for the past 150 years. The earliest records, incidental in nature, were navigational charts. "Grass" was indicated on the charts, especially in harbors, until 1925 when the kelp and eelgrass symbols were combined (Thom and Hallum 1990). Some of the earliest dedicated eelgrass surveys were done by Phillips, especially in Hood Canal. These surveys, conducted in 1962-3, were accomplished by pulling Dr. Phillips, equipped with SCUBA gear, underwater around Hood Canal. This effort remains one of the heroic inventory efforts of all times. These data were only partially published (Phillips and Fleenor 1970).

Although there have been numerous regional or site-specific inventories (Phillips 1984), the first state-wide inventory was performed by Washington Department of Natural Resources and published as the "Washington Marine Atlas" in the early 1970's. Information was collected from a variety of sources dating from the 1960's. The large scale and generalizations of the beds made it useful only regionally. A second state-wide effort was begun in early 1970's and published as the Washington Coastal Zone Atlas (WCZA) (Washington Dept. of Ecology 1980). The information for eelgrass was derived from 1:6,000 scale natural color aerial oblique photographs with the beds published at a scale of 1:24,000 (Gardner 1984). The maps remain the most widely used in Washington. They are, however, highly inaccurate, especially in the subtidal zone. Although information from the WCZA has been digitized and re-published in the Puget Sound Environmental Atlas (Washington Dept. of Ecology 1980; PSWQA 1989; ESRI 1989), the eelgrass data have not been updated (PSWQA 1992). The highest needs are for subtidal inventories. Losses near the lower limit of eelgrass are largely unknown, yet this is the area most likely impacted by water quality degradation and reduced light penetration.

Another unpublished source of information regarding eelgrass in Washington comes incidentally from the herring roe surveys performed for the last 50 years by the Washington Department of Fisheries (WDF). WDF staff routinely raked subtidal spawning areas and noted the presence of eelgrass, seaweeds and roe. These records have never been analyzed, but exist in numerous field notebooks in Olympia.

Current Inventory Efforts

Under the guidance of the Puget Sound Water Quality Authority and its Puget Sound Ambient Monitoring Program (Puget Sound Water Quality Authority 1992), the Washington Department of Natural Resources is inventorying the nearshore habitats of Puget Sound using remote sensing and GIS to acquire, analyze and store the data (Mumford 1992). The primary purpose of this program is to monitor habitats as indicators of the success or failure of water quality programs in Puget Sound. This effort will inventory the entire shoreline of Puget Sound every three years. The project does not include the Strait of Juan de Fuca nor the outer coast and its estuaries, Grays Harbor and Willapa Bay. Eelgrass is one of the high priority resources to be mapped. This information will be useful to local planners as they strive to meet the mandates of the Growth Management Act, and to the Department of Natural Resources in its proprietary responsibilities for state-owned aquatic lands.

Two major federal inventory efforts are underway, Coastwatch (Thomas et al. 1991) and EMAP (Hunsaker et al. 1990). Coastwatch is designed to specifically monitor changes in coastal wetlands, including submerged aquatic vegetation (SAV). The method to be used for SAV monitoring is aerial photography (Klemas et al. 1987). The use of underwater video to inventory subtidal eelgrass beds is currently being investigated in a pilot project (Norris et al. 1994).

Changes in Distribution/Abundance

Spurred by the urgency of the situation in Chesapeake Bay (Orth and Moore 1983), Thom and Hallum (1990) analyzed historical data to determine if there have been long term changes in the distribution and abundance of kelp and eelgrass in Washington. They found reliable information only for the major urbanized embayments and, not surprisingly, major losses primarily due to fill of tideflats (70% loss in Bellingham Bay, 15% in the Snohomish River Delta, but interestingly, a five-fold increase in coverage in Padilla Bay). This last increase may be even more dramatic because early records show no eelgrass in this bay prior to the diking of the Skagit River (D. Bulthuis, pers. comm., 1993).

Summary

Eelgrass serves as an indicator of environmental health (den Hartog 1971) and the functions associated with these plants (e.g. primary productivity, habitat, hydrodynamics) depend upon its presence. Once a reliable baseline map is created, trends in eelgrass abundance can be assessed.

The greatest need is a subtidal inventory. Losses at the lower limit of eelgrass are largely unknown, yet this is the area most likely impacted by water quality degradation and lower light penetration (see Bulthuis, ch. 4). It is ironic that perhaps the most threatened portion of the eelgrass beds are those not being inventoried in any fashion at this time.

Having said this, it is important to note that the inventory of eelgrass is beginning to move from its historical pattern of piecemeal, site-by-site efforts using a variety of methods, to one of creating an information system. A major challenge will be to create and use standard methods necessary to allow comparisons between inventories.

An even more critical challenge will be to make sure the information is available to the users (biologists, planners and site-managers). Interfaces between the information and the user will have to be created. Updated information must be incorporated. All this will require a long-term commitment of funds.

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Appendix: Inventories as Information Systems

A. Business Needs Analysis

1) Define the "job" to be done with the information. Some examples are:

a. Data for biological modeling of primary production, habitat functions, hydrodynamics, sediment stabilization, wave attenuation, or community analysis.

b. Assist in siting, regional planning and cumulative impact assessment.

c. Trend analyses. Trends may be both on a temporal and/or spatial basis.

2) Determine what information and quality of information is needed to do the "job"

a. Spatial accuracy

i. Minimum mapping unit- the smallest area for which data are collected, analyzed and stored. This involves an interplay between the scale and resolution.

ii. Positional accuracy of the information

Absolute accuracy- position in relation to the earth coordinate (latitude/longitude or UTM projection coordinates)

Relative accuracy- the ability to distinguish between different vegetation types (e.g., eelgrass vs. ulvoids, or mixtures of the two) and positioning the line drawn between them. The need will determine what measurement system may be used: traditional surveying, global positioning satellites (GPS), radio location, etc. as well as classification and analysis methods.

b. Temporal accuracy

i. When data are collected

Seasonal variation in the abundance and types of vegetation, particularly in temperate climates; maximum standing crop or maximum growth rate; and degree of fouling by epiphytes all must be considered.

ii. How often data are collected.

Changes in maximum standing crop may also require data collection several times a year (multi-temporal) in order to distinguish between vegetation types, e.g., eelgrass beds tend to maintain a high standing crop year-round while ulvoids and other algae may only present during the summer.

c. Trend analysis

Change in eelgrass bed position, abundance, or species composition. Measurement of these changes is difficult. Inter-annual variation caused by natural phenomena, (El Niño, winter freezes, etc.), are important and make any base-line done on a one-time basis suspect. "Directional" changes may be caused by intrinsic vegetation changes (succession), land-use and other human caused changes, or changes in global climate patterns and sea level changes. Distinguishing one from another is difficult.

d. Tidal height, wave height

e. Water clarity

f. Classification

US Fish and Wildlife Service (Cowardin et al. 1979) is most often used.

g. Definition of an eelgrass "bed"

"Greater than 40 turions/m^2" -Washington definition

The definition of *Z. japonica* beds has not been made. These two species may overlap in their range in the mid-intertidal.

h. Accuracy (Congalton 1991, Lunetta, Congalton et al. 1991)

i. Overall accuracy of the Multispectral Scanner (MSS) classification is given by the sum of the total correct (numbers in the major diagonal) divided by the total number of pixels checked for accuracy.

ii. Producer's accuracy is the probability of a reference pixel being correctly classified by the MSS classification. Producer's accuracy is calculated for each class. A person looking at an eelgrass bed on the water knows that there is a certain chance that bed is correctly identified on the map as eelgrass.

iii. User's accuracy is the probability that a pixel on the map actually represents what is on the ground. A person looking at an area mapped as eelgrass knows that there is a certain chance that there is actually eelgrass on that site.

i. Extent

i. Horizontal (geographical area)
site specific, regional, or state-wide, or national?

ii. Vertical extent
intertidal
subtidal
both?

j. Who will be using the information and what products will they need?

B. System Design and Construction

Once the business needs assessment is completed and agreed upon, the rest of these tasks become much easier and should be turned over to a team of specialists. There should now be concrete criteria for performance and system design, rather than being a guessing game built on unknown assumptions.

C. Data Acquisition

The method of acquisition of the field data used will depend upon the criteria already discussed. In addition, factors such as cost, availability of aircraft, weather, etc. must be considered. Ground-based acquisition can be accomplished using boats or on foot. In a sense, it is remote sensing of the resource, but the scale between the eelgrass and eye is only a few meters and the beds are observed and interpreted directly onto a base map or photo. Because of the spatial placement of the beds, accurate mapping of extent is difficult, although there is seldom any misinterpretation of eelgrass vs. some other vegetation (high classification accuracy but low spatial accuracy). The use of hand-held, continuously-recording global positioning satellite (GPS) units can be used to delineate beds. The base map or photo must be rectified, i.e. have accurate positional marks. The use of unrectified photographs is not advised if the information is to be transferred into a digital database (GIS). Either Ortho-photos (scale of 1:12,000), available from Department of Natural Resources,[2] or USGS quadrangle maps (scale of 1:24,000 7.5') should be used.

Methods for the use of transects to determine turion density and community structure is discussed in Orth and Moore (1983).

Remote sensing data are recorded on film, digital tape or videography, and then analyzed and classified. The data recorder can be mounted on a ground-based platform (tall pole, crane, kite, tethered balloon or dirigible) or free-flying (remote-controlled aircraft, ultralight, manned aircraft, satellite).

The data can be recorded photographically, digitally, or by videography. Photography is the time-tested method and techniques are well established (Orth and Moore 1983). Different film types are used for different applications. Black and white film is seldom used. It is not significantly cheaper

[2]Available from : Photo and Map Sales, Department of Natural Resources, Natural Resource Building, 1111 S. Washington St. Olympia, WA 98504

and there is less information in shades of gray than in colors. Natural color film is widely used. It provides good water penetration so shallow subtidal beds can be seen although eelgrass on dark substrate may be difficult to distinguish. False-Color infrared film is widely used in vegetation mapping because chlorophyll-containing plants appear red. This makes distinguishing vegetation easy. Its main limitation is water appears black and there is no or very little (only if overexposed) water penetration.

Widely used film formats include 35mm (true false-color infrared film not available), 70mm and 9" aerial photographic film. There is a tradeoff between cost and the ability to see small detail in these films.

Cameras are usually used in ground-based systems or aircraft. The issue of oblique vs. vertical photography should be discussed. Flying along a beach and taking photos out the window may enable one to easily distinguish eelgrass beds, but it is very difficult, in fact nearly impossible, to rectify the image to project it on a vertically-based map without ground control points in the image.

The ability to quickly and cheaply digitally scan photographs has increased dramatically in the last few years. Film remains a inexpensive way to acquire and store enormous amounts of information in comparison to direct digital methods discussed below. But the ability to manipulate digital images is so powerful that many want to have that option.

The direct acquisition of digital data can be accomplished by imagers mounted in aircraft or satellites. Aircraft have the advantage of being able to fly at a particular time, i.e. during clear weather and low tides. The resolution of the imagery can be varied by the height of the aircraft. The cost, however, is higher than satellite imagery.

Satellite imagery is obtained commercially from Landsat or SPOT. Resolution (pixel size) for Landsat TM data is 30m and 20m for SPOT. The main drawbacks to satellite imagery are high cost, low resolution, and availability (TM satellites only pass over the study area every 17 days and trying to get a clear day and low tide during the summer growing season is difficult (Webber et al. 1987). In general, the minimum mapping unit is a 3x3 pixel unit (90m on a side or nearly a hectare (2.5 acres)). Strip eelgrass beds only 3-10m wide may not be visible in this imagery. The data are usually well georeferenced, however.

The type of sensor is also important, not only for pixel size, but also for geometry and hence ability to georeference the image, and derive spectral resolution. Scanners such as those made by Daedelus acquire each pixel sequentially and thus each pixel has a separate geometry, making georeferencing nearly impossible. Pushbroom scanners have similar line geometry, making georeferencing easier. Chips such as the charge couples device (CCD) have a three dimensional geometry, similar to photographs and can be georeferenced in a similar manner. Each device has a different number of spectral channels, some of which can be changed.

Videography has the advantage of being very inexpensive in comparison to other scanners. Commercially available equipment can be used. Commercial true-color cameras can be mounted in a variety of platforms, and multi-camera arrays for multichannel acquisition are available. Frame-grabbers can be used to transfer data into image processing software. Videography has been used with underwater sleds or platforms (Jim Norris, pers. comm.). Side scan sonar has also been used to map underwater vegetation. A major problem has been the ability to ground truth the information and to determine if the images are truly eelgrass or kelp.

D. Ground Truthing

Ground truthing is an integral part of any remote sensing inventory. First, it is essentially the verification process to check the accuracy of information. Second, ground truthing information is gathered for training sets in computer analytical procedures or for training of photointerpreters. The same data must not be used for training and accuracy assessment. Sample size is discussed in Congalton (1991).

E. Data Analysis

Photointerpretation

Photographic images are visually inspected and the eelgrass beds marked either on the photo or in direct digitization. The use of stereoscopic pairs of photographs, in spite of the very low relief of the features, add important texture to the image, making identification easier.

Computer-aided classification
The classification of images is done by a number of software packages (ELAS, LAS, ERDAS, etc.) An excellent discussion of the techniques used appear in Lillisand and Kiefer 1979; Moik 1980; Schowengerdt. 1983; Jensen 1986; Ryerson 1989.

F. Data Storage

Life span of the data
In biological systems the usefulness of the data may be fairly short, in the order of several years, depending upon the rate of change in the area.

Longevity of the storage medium must be considered. Magnetic tape lasts only about 10 years before degrading, optical storage may last up to 50 years. Paper maps, on the other hand lasts for hundreds of years when properly stored.

Assure current and future data compatibility
The exchange of digital data require not only software and hardware compatibility, but the methods of collection and data base structure must be well documented. Technology is rapidly changing and the use of arcane, home-brew, or non-standard software/hardware should be discouraged. Given that there is often a high cost associated with creating an inventory, all these become especially important.

G. Product Delivery

1) Output or products

a. Digital tabular spatial data make geographical information systems (GIS) coverage (raster or vector) analyses and updating relatively easy.

b. Paper (hardcopy, maps)

2) One-time or ongoing

H. Maintenance

Determine if the inventory is to be a one-time or ongoing project. If digital data are involved, there will be a need to update the information, distribute information (tapes, disks), and answer questions.

I. Documentation

Documentation of the entire process must be maintained and published with the data. An excellent example of what can go wrong if poor documentation is shown in (ESRI 1989). Documentation should include the QA/QC plan and information about how the data were collected, scale, map projection, coordinate system, etc.

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6. Seagrass Management In Washington State

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In this paper I briefly describe seagrass (*Zostera marina* and *Z. japonica*) management in Washington State and suggest ways the current system could be improved. The Washington State Department of Fisheries (WDF) began to manage seagrass habitats in the late 1970's and early 1980's. During this time WDF and other regulatory agencies began to specifically protect seagrass habitats. The focus of early management efforts was protection of those *Z. marina* populations that are used by Pacific herring (*Clupea harengus pallasi)* as spawning substrate.

Since the early 1980's, habitat managers have become increasingly protective of seagrasses, primarily as a result of three factors. First, there has been a national trend toward greater environmental protection. Second, research conducted in this region has demonstrated that seagrass is an important habitat for fish and wildlife. Third, seagrasses have become increasingly threatened by shoreline development. Although there have been changes in the abundance and distribution of seagrass in some areas of the state, it is difficult to determine whether changes are the result of shoreline development or other factors, such as long term environmental changes.

A number of shoreline activities can potentially affect seagrasses in Washington, including water quality changes, dredging and filling, construction of bulkheads, and overwater structures such as piers, docks and floats (Phillips 1984, Thom 1990). A list of projects and their actual and potential impact to aerial extent of eelgrass appears in Table 1. Of these, marinas which typically involve several different types of impacts (e.g., dredging and water quality changes), account for the greatest losses of seagrass . The loss of seagrass resulting from some activities is unknown. For example, numerous small piers and docks that shade seagrass, have been built in the state. The number of these structures built is not presently known, but in some areas (e.g., the San Juan Islands) it is clearly substantial.

Many, often conflicting, factors affect the management of marine resources. One factor of particular importance is science. Science has provided information on seagrass biology and ecology, restoration techniques, functions, and the effects of shoreline development. The increase in our knowledge about seagrass habitats in the region has played a crucial role in the evolution of seagrass management. Although much has been discovered about seagrasses in Washington, a great deal more remains to be learned. Information gaps include 1) natural patch dynamics, 2) methods for mitigating impacts to seagrass, 3) the dependence of seagrass functions upon other surrounding habitats, and 4) additional functions of seagrasses.

Table 1.
Projects in Washington State where seagrass is an issue. Projects selected were those that have been active since 1988. Active was defined as a project where an Hydraulic Project Approval (HPA) or COE permit was applied for or granted, an EIS was issued or is being developed, a developer officially contacted WDF about a project, or impacts to eelgrass are dealt with in a management plan. For some projects, information was incomplete.

Project	Year	Status	Amount
Lummi Bay Marina	1982-90	NA	8.00
Figalgo Bay Marina	1979+	NA	14.00
Ship Harbor Marina	1985+	O	17.00
Development Ventures	1990+	O,M	0.50
Elliott Bay Marina	1985+	O,M	0.25
Swinomish Marina	1988+	O	2.00
Pt. Townsend Marina	1988+	NA	1.50
John Wayne Marina	1979+	O,M	2.00
Roche Harbor Marina	1991+	O	1.00
Port of Skagit Co.	1990+	O,M	0.10
Port of Bellingham	1990+	NA	2.00
Cape Sante Marina	1990+	O	1.00
Islander (Lopez Is.)	1992+	O	0.25
Ivar Jones Marina	1993+	O	20.00
Grays Harbor Widen	1980+	O	20.00
Trident Seafoods	1988+	O,M	0.25
Youngsman	1978+	O	0.20
Union Wharf	1989-92	NA	0.10
West Point Expansion	1988+	O,M	0.10
Ocean Spray Pipeline	1989	?	?
Clinton Ferry Dock	1992	O	0.50
Esplande (Magnolia)	1993+	O	11.00
Manchester Fuel Dock	1986+	O	?
Single Family Piers 5+	1990+	O,M	0.50
Texaco Oil Spill	1990+	O	?
Spartina Mgmt.	1991+	O	?
Beach Graveling	1989+	O	?
Fishing (Comm, Rec)	?	O	?
Oyster Culture	1850	O	200.00?

*NA = No activity on the project as of June 1993. M = A mitigation plan has been accepted or is in progress. O = Ongoing. The project is still active.

Of these issues, probably the most important to WDF is increasing our understanding of how to mitigate impacts of shoreline development on seagrass. Resource agencies, at present, have adopted an aggressive "no net loss" policy for seagrass. Mitigation proposals are evaluated based upon the risks to resources and the likelihood of mitigation success, and generally, permits are not issued to a developer unless there is a high probability that impacts can be successfully mitigated. One reason for this policy is that the history of seagrass transplanting in the Pacific Northwest has not been encouraging (Thom 1990). Resource agencies have responded to this situation by tightening mitigation requirements. Currently, mitigation that either appears to have a high chance of failing or that might impact critical resources, typically requires full, upfront mitigation or a demonstration that the mitigation will be successful. This can extend the project timeline many years. Before these resource agencies can be expected to relax their current approach, basic research to improve transplant success in the Pacific Northwest is needed.

A second factor that influences seagrass management is the specific groups or entities that are involved in particular seagrass issues. The groups involved depend on the specific issues associated with a project, such as location and whether public lands are involved. Each entity has specific authorities that define the breadth of their role on a project. I believe that the most important organizations are WDF and the U.S. Army Corps of Engineers (COE), because these agencies have broad authority allowing them a role in the greatest number of seagrass projects.

A third factor influencing seagrass management is policy or course of action. To my knowledge, the only seagrass policies that exist in Washington are informal (i.e. not officially adopted or not written). There are, however, a number of other policies that exist that are directly relevant to seagrass management. For instance, WDF has regulations that prevent the destruction of eelgrass used for herring spawning.

A procedure that most regulatory agencies follow in managing seagrass is called "sequencing." Sequencing is a systematic way of working through a proposed project to ensure that impacts are first avoided where possible, minimized if they cannot be avoided, and then compensated (i.e. mitigated). Only those impacts that are unavoidable should necessitate mitigation. A diagram depicting how this process is generally applied in WDF is shown in Fig. 1.

There are a number of ways that I think seagrass management can be improved in the future. First, science can help by filling some of the critical information needs mentioned earlier. The most important, in my viewpoint, is a better understanding of how to restore and mitigate impacts to seagrasses in this region.

Other needed improvements in seagrass management are non-scientific and may include increased communication between agencies and user/client groups. This may help increase the public's confidence in seagrass management practices. Client/user groups often do not understand why particular decisions are made on projects (e.g., why transplantation is permitted in one project, but not in another). This case-by-case approach has made it difficult for the public to use the past to predict how new projects will be managed. This, in turn, has generated some concern about whether agencies are consistent in their management. I think that agencies are consistent in how they manage seagrass projects, but differences in authority, the specifics of each project, and the desire to achieve "no net loss" result in the appearance of inconsistency.

Another improvement is the development of policies that are specifically oriented towards protection of seagrass. Included in this should be the development of a formal mitigation policy that lays out mitigation ratios, timelines, monitoring procedures, and other important factors.

Finally, a system of monitoring the progress of specific seagrass projects is needed. This would include a computerized system that would allow specific projects to be tracked and maps depicting possible changes in seagrass distribution and abundance to be developed. We do not know if management efforts are achieving the desired goal of "no net loss". Until we know this, it will be difficult to determine if other changes in management might be warranted.

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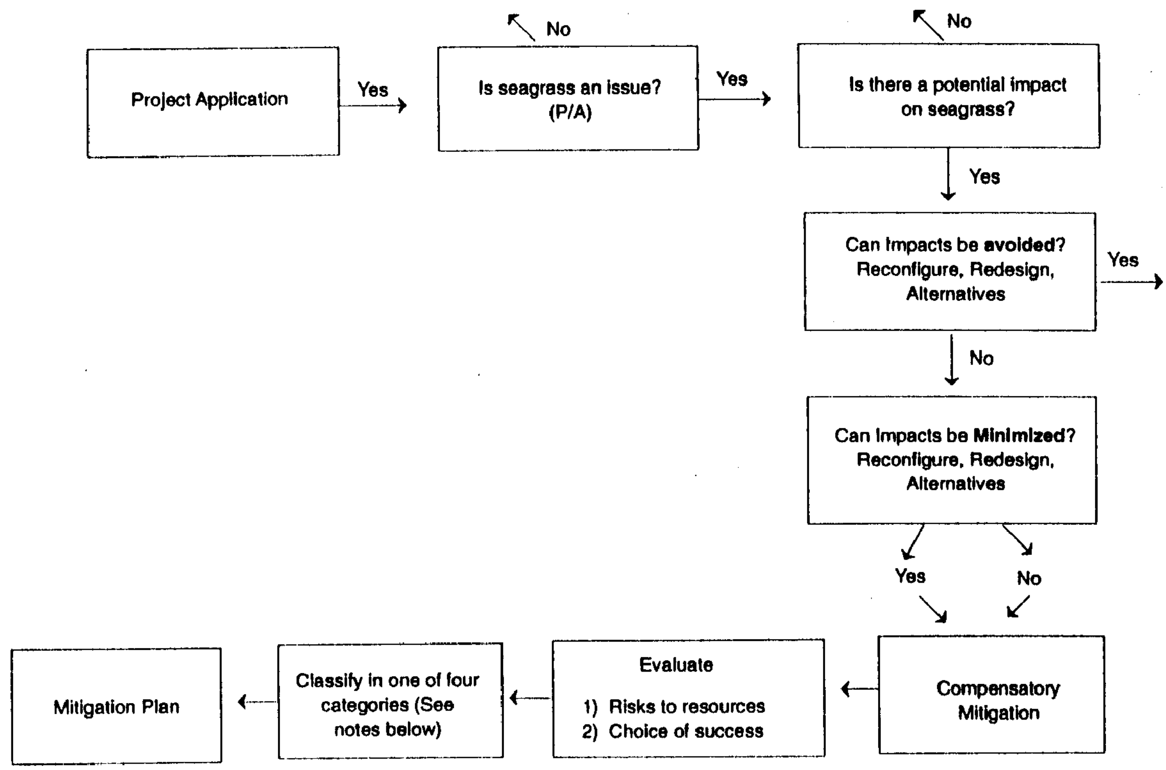

CATEGORY 1

- Project and mitigation can proceed simultaneously
- <0.25 acres of eelgrass impacted
- Critical resources are not involved
- Mitigation has high chance of succeeding
- Mitigate at a ratio of at least 1.5:1

CATEGORY 2

- Demonstration of success is needed or mitigation is needed upfront
- One of these conditions is met:
    - >0.25 Acres of eelgrass impacted
    - critical resources are potentially impacted
    - chance of success of the mitigation is low
    - contingencies are inadequate
- Mitigate at a ratio of at least 2:1

CATEGORY 3

- Project not allowed to proceed
- very critical resources are involved

CATEGORY 4

- Significant scientific benefit possible
- Project and mitigation can proceed under certain circumstances.

Figure 1. **Unofficial WDF seagrass management model.** The system WDF generally uses to handle a seagrass project.

7. Restoration Of Damaged Eelgrass Habitats

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Eelgrass (*Zostera marina* L.) has undergone substantial declines in many areas of the world (Bulthuis, ch. 4, and Short and Wyllie-Echeverria, *in prep.*). In the Pacific Northwest, changes over time are difficult to assess because baseline data are lacking, but local declines in urbanized bays are documented (Thom and Hallum 1990). Eelgrass habitats are also under continuous pressure from shoreline development. I estimated in 1991 that 17 development projects, potentially impacting a total of at least 3,061 ha in Washington State, were proposed. To mitigate the impacts to eelgrass, development of new eelgrass meadows through transplantation is often proposed (Thom 1990). Although transplantation can be successful on a small scale (i.e. 1 m^2), larger-scale efforts generally have poor success (Thom 1990). Poor success has led to low confidence among resource agency personnel in the ability to restore or mitigate eelgrass losses through transplantation. This low confidence has resulted in the denial of development permits and general frustration among developers, agency scientists and eelgrass researchers.

There are a number of lessons that have been learned from past efforts to transplant eelgrass, and these can be used in conjunction with the growing field of ecosystem restoration for enhancing the probability of successfully restoring damaged eelgrass meadows. I discuss below some key considerations for restoring eelgrass meadows. The information was compiled through the development of materials for a course on wetland restoration for the National Oceanic and Atmospheric Administration.

Definition of Restoration

Restoration may be defined as returning a system to a former, normal or unimpaired state. "Predisturbance" condition is a term commonly applied to this state. However, because disturbances are an integral part of the natural processes in ecosystems, "predisturbance" is not a valid concept. The natural state of an eelgrass meadow may range widely in terms of shoot density, biomass, productivity, seasonality, reproductive condition, and a variety of other parameters. Perhaps the best goal for restoration is to return a meadow to conditions occurring in a local meadow that receives or has received very little human impact. The goal of any restoration efforts must be well thought-out in the context of the ecosystem.

Criteria for Intervention

When should a system be restored? How can we determine what is required to restore the meadow? Steps to answer these questions have come from a working group of scientists that developed a habitat restoration research plan for the U.S. Environmental Protection Agency, Corvallis Environmental Laboratory, in 1991. The steps are posed as questions in Table 1.

Table 1

Questions to pose in restoring an eelgrass meadow

1. What needs to be done to restore Site X?

2. What is the time frame of restoration?
   - Biological/Ecological
   - Socio-political (funding)

3. What are the objectives of restoration?
   - Aesthetics
   - Species Composition
   - Ecological Integrity
   - Critical (urgent)
   - Landscape

4. Why is it the way it is now?
   - Disturbance History

5. What will happen if no restoration action is taken?

6. What actions must be taken before restoration can be initiated? (cleanup, remediation)

7. What criteria do we use for success?

8. Can we rely on initial restoration actions and early results to predict final outcome?

Siting and Design of Restoration Projects

The site will make or break a restoration project (Thom 1990). Eelgrass requires a relatively specific set of environmental conditions, and the meadow must be appropriately placed within the ecosystem and must be of adequate size and shape to best provide habitat and food resources to animals, and to supply organic matter to the detrital food web. Landscape ecology presents a viable method for siting and designing eelgrass meadows (Table 2). The major problem with the use of landscape ecology principles for this purpose is that many of the empirical relationships that could be used in planning are not well-quantified. Examples include the relationship between patch size and number of animals species, and shoot density vs. number of animal species.

I have found several aspects of landscape ecology useful in planning habitat restoration projects. Most of these are taken from a close reading of Forman and Godron (1986). The main aspects are shown in Table 2. A primary goal of most restoration projects should be to establish a self-maintaining system that functions optimally within the context of the landscape. To do this, habitat size, connectivity and resilience are important siting and design considerations.

Criteria for Successful Restoration

What are the criteria for success? How should success be measured? What level of success is acceptable? Is functional equivalency a viable concept and how does it relate to success? Is it appropriate to require monitoring for the entire period of time it may take a system to fully develop (i.e. 80 years)? The fact is that scientists and regulators are still struggling with these questions. We

Table 2

Aspects of landscape ecology that can be used in siting and designing eelgrass restoration projects.

Patches

A patch is a nonlinear surface area differing in appearance from its surroundings.

A matrix is the surrounding area within which the patch occurs. A matrix is the most extensive and most connected landscape element, and therefore plays a dominant role in the functioning of the landscape.

Aspects of Patches:

1. Size - from Island Biogeography
   $S=CA^z$
   S= Number of species
   C= Constant varying amoung taxa and unit of measurement
   A= Area
   Z= Constant which falls between 0.20 and 0.35
   S=f(+Habitat diversity within the patch OR + Disturbance of the patch + Area of the patch - Isolation of the patch from sources of species $\pm$ matrix heterogeneity - boundary discreteness)

2. Shape
   Primarily related to edge effect
   A. Different species composition
   B. Different productivity
   C. Export-import Process
   D. Access by Animals and Plants

   Measured by interior-to-edge ratio
   A. Edge and interior species - fish and crab behavior
   B. Show figure of effects of patch shape
   C. Small patches may act as edges
   D. Edges function differently from interiors

3. Patch Number and Configuration
   Single large patches often contain more species than several smaller patches, although more species are found in several patches if the patches are widely scattered.

Corridors

A corridor is a narrow strip of land that differs from the matrix on either side.

1. Connectivity is a measure of how connected or spatially continuous a corridor is, which may be quantified by the number of breaks per unit length of corridor. Connectivity is the primary measure of corridor structure.

2. Corridors function as
   A. Habitat for some species
   B. Conduit for movement along corridors
   C. Barrier or filter
   D. Source of environmental and biotic effects on the surrounding matrix

Disturbance and Stability

1. Stability - Long term variability is respresented by a straight line
2. Persistence - Time period during which a certain characteristic of a landscape continues to be present
3. Resistance - Abiltiy to withstand variation due to disturbance
4. Recovery or resilience - Ability to bounce back after disturbance
5. Landscape Dynamics - Patterns of change in matrix and organization of the landscape over time depends on level of force affecting the landscape and at what scale

Forman and Godron 1986

cannot fully answer all of them at present due to lack of data, but that we can make a stab at some of them.

It is useful to envision how an engineer might handle the question of success about a project. If you were to ask an engineer if the bridge he or she designed was successful, the response would be couched in terms of facts relating to how well the bridge performed the job it was designed to do. If the bridge supported the traffic, was durable, low maintenance, and would predictably continue to function well for the life of the project, the engineer would probably judge the project a success. If an earthquake shook the region, and the bridge withstood the shock within limits of the design, then the project would be successful.

Seagrass restoration or mitigation through transplantations can and probably should be judged in similar terms. Did the project meet design criteria? Is the transplanted eelgrass bed expected to continue to develop through the life expectancy of the project? Can it withstand disturbances for which it was designed? I believe that we have enough information on what constitutes a functioning patch of eelgrass to judge whether the patch is functioning as hoped. The latter two questions are, however, problematical from the standpoint of judging success. We do not have a good track record for success of projects, and long-term studies are essentially non-existent. We know that very large projects usually fail and that very small projects, if done carefully, usually persist. We simply do not have an ability to predict the life expectancy of a project. Perhaps we could evaluate life expectancy in light of natural meadows. For example, how often does a meadow receive a disturbance that is so great that the meadow is totally destroyed? In Padilla Bay, winter freezes and heavy wind events occur almost every year, and damage to the Padilla meadow can be significant. The size of the meadow is an effective buffer from this disturbance and recovery occurs from recruitment from intact portions of the meadow. Smaller meadows may not be so lucky. The lesson we can learn here is that large meadows that are located under appropriate physical and chemical conditions probably can survive frequent and severe disturbances. We need more information on transplanted and natural small meadows in terms of their disturbance frequency and recovery rates and processes. Perhaps we could design a transplantation project to be able to withstand the 10 year wind storm (or some other periodic disturbance). At least we would have a target design criteria analogous to the bridge engineer.

Challenges

The greatest challenges are to:

1. improve the success rate for eelgrass meadow restorations,
2. understand the requirements for eelgrass,
3. develop and test technologies for successful establishment of eelgrass,
4. increase the predictability of our actions in restoring eelgrass meadows, and
5. understand how meadows best fit physically and ecologically within the context of the landscape.

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FRAMEWORKS FOR ANALYSIS OF THE ISSUES

Environmental policy and scientific research should be mutually supportive (Lubchenco et al. 1991, Lee 1993). In this section we present two parallel and interdependent approaches (see Fig. 1) to defining priorities for policy development and ecological research regarding seagrasses in the Pacific Northwest region. Hershman and Lind develop a systematic analysis of legal and institutional arrangements that govern resource uses and the impacts of human activities. They evaluate existing seagrass policy to identify gaps and set priorities for new policy development. Similarly, Olson and Straub present an approach to quantifying trends or biases in existing research on eelgrass, in order to target previously under-represented or emerging research topics and approaches. Ultimately, we plan to bring the two analyses together to jointly evaluate the need for policy changes and scientific research. Specifically, the management needs identified by Hershman and Lind will become criteria for priority-setting for ecological research, and emerging trends in ecological research identified by Olson and Straub will suggest new areas for policy development.

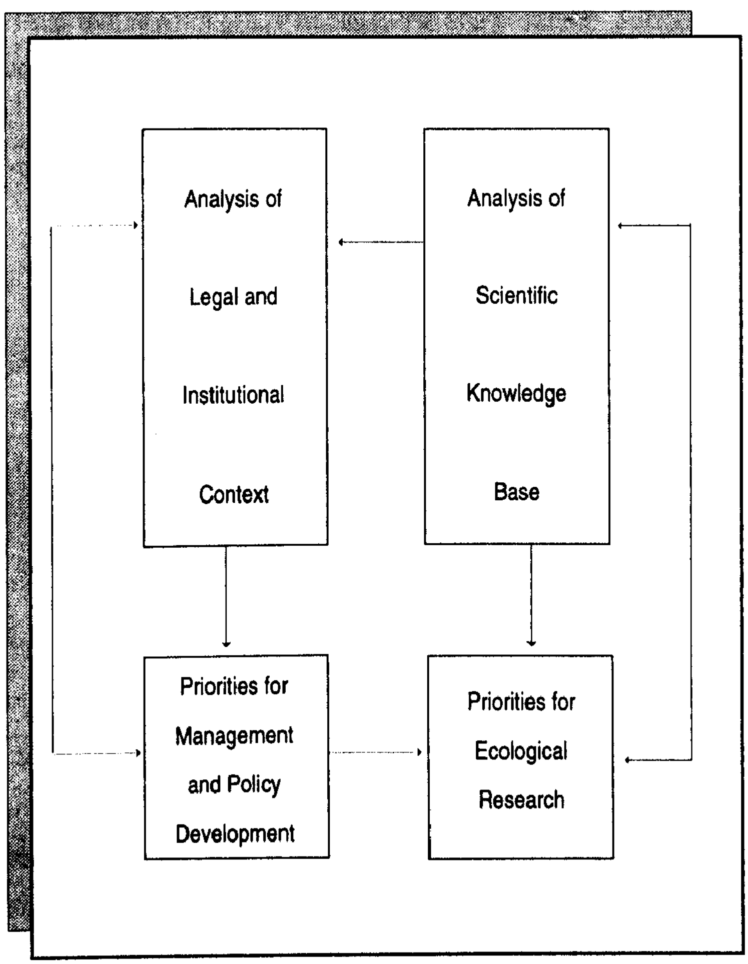

Figure 1. **Frameworks for analysis of management and scientific issues.**

8. Evaluating and Developing Seagrass Policy in the Pacific Northwest

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The intent of this section is to present a framework for the analysis of the legal and institutional context for seagrass science and policy development. Such an analysis helps establish priorities for management and for ecological research (Fig. 1 on previous page). In turn, the scientific knowledge base informs the legal and institutional context. Our discussion proceeds in two steps. First, we provide a brief overview of seagrass protection and management policies in the Pacific Northwest, (Fig. 2) illustrating the scope of current policies and suggesting criteria for evaluating their effectiveness. Second, we suggest several steps decision-makers should take in designing, implementing and evaluating new seagrass policies. These steps are outlined in the form of five questions (Fig. 3). Our basic premise is that government capacity to manage natural resources and the environment is stretched to its limit and choices must be made. Even worthwhile new seagrass policy initiatives must be evaluated in comparison with other pressing policy needs, and in terms of the personal and budgetary resources available to implement the policies.

Evaluating Current Seagrass Policies in the Pacific Northwest

In Figure 2 we pose the question "Are seagrasses adequately managed under current policies?" and outline the scope of agencies and polices involved in the protection and management of seagrasses in the Northwest. Most striking, perhaps, is the diffusion of seagrass management activities among a wide variety of agencies at every level of government. This is due, in part, to the fact that most of the policies listed in Figure 2 are aimed at managing various types of human activity rather than managing a particular resource such as seagrass. Among the different types of policies we have identified are:

Project Review. This type of policy is conducted by a variety of agencies at all levels of government. Fresh (ch. 6) suggests that in Washington, the State Department of Fisheries (WDF) has taken the lead in reviewing development projects for possible threats to seagrass resources. We have found that some counties (e.g., San Juan and Whatcom Counties) are also adopting seagrass protection in their shoreline master programs.

Question

Are seagrasses adequately protected and managed under the current policies?

→

Review of Policies

Project Review
Agencies: COE, EPA, WDOF NMFS, USFWS, local gvt's
Policies: (NEPA, Sec. 404, Sec. 10, HPA, CZM, GMA, etc.)

Water Quality
Agencies: EPA, Ecology, PSWQA, local govt's
Policies: Nonpoint source, NPDES, CWA, Stormwater programs, monitoring

Public Land Mgt.
Agencies: DNR, DOD, Tribes
Policies: Protection, cultivation, inventory, leasing, etc.

Restoration/Habitat Development
Agencies: EPA, NOAA, USFWS, DNR, Ecology
Policies: NRDA, CERCLA, Mitigation

Damage Reduction
Oil spills, infestation, disease, etc.

Inventory and Mapping
NWI, DNR, NOAA, GIS

→

Criteria for Evaluating Policies

- Is the relative importance of the resource properly understood? (Ecological, economic, political, cultural)
- Is the status of the resource properly understood? (adequate information on abundance, trends/shrinking or growing, lost functions, potential threats?)
- Does the agency/policy have appropriate geographic scope?
- Does the agency/policy regulate appropriate activities?
- Adequate funding?
- Conflict or cooperation with other agencies or policies
- Adequate powers?
- Do policies compare with trends from other jurisdictions?

→

Basic Premise

Many policies are needed but gov't capacity is stretched to its limit. Choices must be made.

Decision

NO:
Current Policies do not adequately protect seagrass resources.

YES:
Current Policies are adequate

→

Policy Options

- Change/upgrade existing policy
- Initiate new policy
- Combination of above
- No change

Figure 2. **Evaluating current seagrass policies in the Pacific Northwest.**

Water Quality. In the Pacific Northwest, threats to seagrass from water quality degradation are not as well documented as for Atlantic waterbodies such as the Chesapeake Bay (Bulthuis, ch. 4). Nevertheless, National Pollution Discharge Elimination System (NPDES), nonpoint source and stormwater management programs may directly affect and improve the health of seagrass resources.

Public Land Management. These are policies of the state, federal and tribal agencies that own the submerged lands that support most seagrass beds. Policies may include such activities as protection, cultivation and leasing.

Restoration/Habitat Development. In recent years, a variety of agencies have implemented aquatic restoration and habitat development projects. Restoration of seagrass beds may be included in some of these projects. Often restoration is required as part of mitigation requirements attached to particular development projects.

Damage Reduction. Oil spill cleanup regulations are an example of this type of policy. As the technology of seagrass transplanting and restoration advances, seagrass restoration may play a larger role in the cleanup of spills.

Inventory and Mapping. According to Mumford (ch. 5) Washington State Department of Natural Resources (DNR) has completed seagrass inventories for most of Washington's intertidal zone. However, most seagrass beds in the subtidal zone have not been inventoried. Even mapping programs such as those conducted by the National Oceanic and Atmospheric Administration (NOAA) and the National Wetlands Inventory do not routinely include seagrass resources.

To evaluate these current policies, adequate criteria must be chosen. Various criteria that may prove useful are listed in Figure 2. For example, geographic scope may be an appropriate evaluation criteria. Many current agencies and policies may lack the necessary geographic scope to effectively protect seagrasses. Shoreline management programs have jurisdiction over shallow water areas. Typically, however, shoreline programs neglect intertidal and subtidal resources and put all their attention on land use activities in the first 200 feet of shorelands. By contrast, water-oriented agencies (e.g., Corps of Engineers (COE) and DNR) may not extend upland enough to cover seagrass species that inhabit shallower intertidal zones, or regulate upland activity that can impact subtidal zones.

A decision is needed after asking the basic question: Are seagrasses adequately protected and managed under current policies? The lack of basic information on the status of the resource, especially in the subtidal zone, may suggest further study. In general, federal and state jurisdiction exists over seagrasses under laws such as §404 of the Clean Water Act and the State Hydraulics Act.

However, we found no specific policies for managing seagrasses in the Northwest, although one is under consideration by WDF (Fresh, ch. 6). Seagrass issues emerge primarily at the project review level. Other regions such as the Chesapeake Bay and Southern California have more extensively developed seagrass policies. For example, the Chesapeake Bay Program proposes establishing minimum light requirements for seagrasses and now uses the health of seagrass beds as a primary water quality indicator in the Bay (Dennison et al. 1993). In Southern California, the National Marine Fisheries Service has established policies to govern seagrass transplanting for compensatory mitigation (Robert Hoffman, NMFS, Southwest Region, pers. comm.).

Designing, Implementing and Evaluating New Seagrass Policies

Figure 3 illustrates the type of policy process that is warranted if it is decided that current policies are inadequate and policies specific to seagrass resources should be created or amplified. We have diagrammed the design, implementation, and evaluation of new policies as a five-step process using five basic questions that should be asked during the process:

1. What are the alternative policies that could solve seagrass problems?
2. Which alternative is preferred and should it have priority over other policy needs?
3. How is a seagrass policy designed?
4. How is a seagrass policy implemented?
5. Is the seagrass policy working?

We use two examples of possible seagrass policies to illustrate the policy process outlined in Figure 3. One possible policy alternative might be to stress transplanting to mitigate for damages to seagrass beds. However, WDF now believes that Pacific herring may not be able to utilize transplanted seagrass beds for spawning nurseries. In addition, the cost of transplanting may prohibit any large scale projects. The result of a thorough policy analysis of seagrass transplanting may, in fact, produce restrictions on transplanting that discourage its use.

A second policy alternative may be for an agency with a broad stewardship mandate such as the DNR to take the lead in seagrass management. DNR may have advantages over other state and federal agencies, because it owns much of the submerged lands with seagrass beds. In addition, DNR is not necessarily project-oriented in its approach to management. By contrast, WDF and COE only act in response to development projects, where there is a threat to existing resources. As steward of the state's submerged lands, DNR has a broader mandate to intervene in response to natural or man-made threats to the resource that may not be project or development-oriented. Typical policy examples might be:

- Restrictions on boating where propellers may disturb critical seagrass beds.
- Programs to control invasive species that threaten native seagrass beds (e.g. *Spartina* infestations in Willapa Bay).

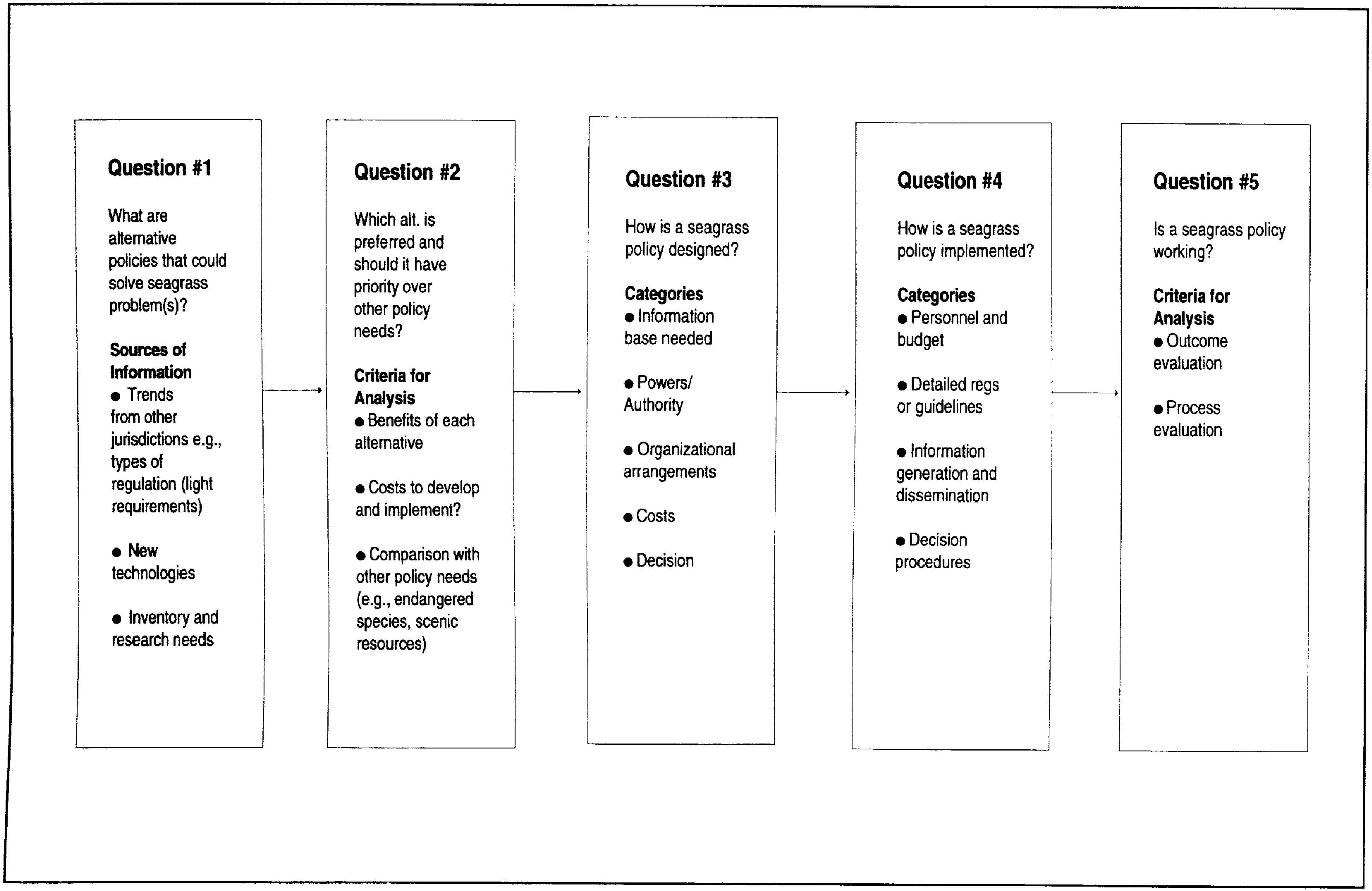

Figure 3. **Designing, implementing and evaluating new seagrass policies.**

- Nonpoint source pollution programs where water quality problems threaten seagrass beds (e.g. Chesapeake Bay).
- Restoration of degraded seagrass beds by transplant or protection policies.
- Policies dealing with cumulative impacts that might degrade seagrass resources. Cowper (1979) reviewed state and federal laws touching upon the management of seagrass beds and concluded that the establishment of management plans for seagrass would be consistent with most states coastal zone management programs. Such plans could be adopted by regulation in most states without resorting to the cumbersome legislative process.

Conclusion

This section has presented a few brief thoughts on possible seagrass policy in the Pacific Northwest. It does not represent extensive research into current policies or possible initiatives. Figure 1 illustrates the current scope of management activities that relate to seagrasses. A wide variety of policies already exists, but most are responses to human threats to the environment, rather than specific seagrass management programs. For this reason we conclude that there is no need for a major overhaul of the regulatory system just for seagrasses. However, it would be valuable for the aquatic lands program in DNR to be upgraded to facilitate stewardship of submerged lands. Other chapters in this volume have identified areas where increased research or enhancement of seagrass programs may be justified. Mumford (ch. 5) has pointed out the gaps in current resource inventories. Fresh (seminar presentation) has described our lack of knowledge about the relationship between spawning Pacific herring and particular seagrass beds. Seagrass transplanting (Thom, ch. 7) is another area that may warrant further research.

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9. Ecological Models In Research On Eelgrass: An Approach To Setting Research Priorities

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The goal of this paper is to describe a new, quantitative method for setting ecological research priorities for *Zostera marina* (eelgrass) dominated systems. As a supplement to the use of "expert opinion" to develop a research agenda, our approach attempts to systematically identify trends or biases in existing research, and to target under-represented research topics and approaches. Our ultimate goal is to identify areas of overlap between science-driven and policy-driven research questions. This will be a two-step process: The first step, outlined in this paper, is a quantitative and qualitative analysis of the scientific knowledge base. Here, we propose to create a "map" of current scientific information on the ecology of eelgrass-dominated ecosystems, with a set of "overlays," indicating the quantity and quality of information on different aspects of the system. We will also use existing ecological theory to predict which types of human activities have a high potential to result in unanticipated outcomes, given what is currently known about the eelgrass system. Second, in a subsequent paper, we will use the management priorities identified by Hershman and Lind (ch. 8) as a policy-oriented "overlay" on our set of scientifically defined research priorities to target research topics that both address fundamental ecological questions and contribute to the management of eelgrass dominated ecosystems in the Pacific Northwest.

Ecological Models In Environmental Decision-Making

Ecological knowledge forms one of the scientific bases for predicting and assessing environmental impacts and for recommending regulatory management or restoration alternatives (Lubchenco et al. 1991). The same ecological models (Boxes 1 & 2) that are used to explain environmental impacts also form the causal basis for taking particular corrective actions. More specifically, ecological models *define environmental problems* in terms of particular sets of causal variables; they *determine the appropriate methodology* for assessing impacts and monitoring environmental change, specifying data needed and criteria for assessment; and they *constrain the set of corrective actions* to those addressing variables in the model. Thus, the success of environmental planning and management activities depends, in part, on the adequacy of the implicit or explicit models that depict how human activities might cause environmental outcomes. Additionally, the ecological models invoked in the policy arena *define the agenda for further research.* Because both environmental decision-making and the discovery of new ecological knowledge will thus depend on the particular model adopted (Botkin 1990, Pimm 1991), we are interested in identifying the prevailing conceptual models (Box 1) in ecological research on eelgrass.

Ecological Models In Research On Eelgrass—Goals And Approach

In order to determine what models are being tested in current research on eelgrass, we have (1) conducted a comprehensive search of studies published in both the peer-reviewed and "gray" literature, (2) developed the ZOSTERA database (Appendix, page 57) for cataloging and classifying studies, and (3) begun to classify studies and enter them into the database.

We will analyze the ZOSTERA database to identify ecological research priorities, using three primary criteria—research effort, research quality, and ecological complexity. We will quantitatively assess "research effort," the absolute number of studies conducted, by class of model, or ecological paradigm (see Box 1) and by specific models, or pairs of variables (see Box 1), to detect trends and gaps in the types of models tested. One product of these analyses will be a "map" of ecosystem elements (e.g., eelgrass; associated epiphytes, herbivores, carnivores; and physical factors affecting eelgrass beds). On this map, research effort (i.e., numbers of studies) will be indicated by the width of the lines linking ecosystem elements. Research topics which are currently under-studied will thus be highlighted, allowing decision-makers to direct research funds toward promising new research questions. The second type of analysis will address "research quality," indicative of the relative reliability of the available results. Indicators of research quality include

- Approach (tradeoffs exist in precision and generalizability

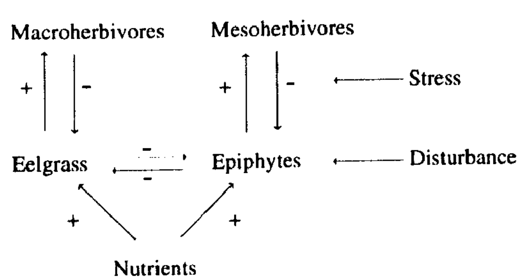
Box 1

What is an ecological model?

An ecological model can be thought of as a hypothesis about how one ecological element or process affects another. For the purposes of this study, we define a model as any pair of variables (dependent and independent) linked by a putative causal relationship. A lab or field study of the relationship between variables X and Y is a test of a model about the causal relationship between X and Y. Thus, models are hypotheses about the relationship between

- resources and populations
- competing populations
- consumers and their prey
- abiotic factors and any component of the ecosystem

A SET OF MODELS LINKING EELGRASS, EPIPHYTES, AND HERBIVORES



Note that in most cases, either variable in the pair may be the dependent or independent variable, depending on the design and interpretation of the study.

We have identified six main classes of models or ecological paradigms, in which ecological processes are thought to be controlled by (1) availability of resources such as nutrients, light or prey items (Bottom-up models), (2) predation (including herbivory) and/or predator-avoidance (Top-down models), (3) physical disturbance, such as sedimentation or erosion, (Disturbance models), (4) physiological stress, such as desiccation or toxic contamination (Stress models), (5) the timing of events, such as seasonal or tidal variation (Temporal models), or (6) the spatial pattern of ecological elements or processes, such as patch size or distance between patches (Spatial models).

between experimental vs. lab approaches)

- Replication (studies with higher replication are more sensitive to subtle changes; some studies are "pseudoreplicated" due to deficiencies in design, invalidating the statistical analysis of the results)
- Duration, frequency of sampling (studies of longer duration and more frequent sampling are more likely to "pick up" environmental variability)
- Geographic scope (broader geographic scope permits more generalizability of results)
- Complexity of design (if external factors are controlled or manipulated, the conditions under which the results will hold are more easily predicted)
- Congruence among results (if results of several studies are congruent, the conclusions of those studies are more robust than if conflicting results have been observed)

Using these analyses, we will produce a set of "overlays" that relate research quality to research effort, highlighting areas of the scientific knowledge base that would be enhanced by improvements in study design, scope, duration, etc.

Third, we will use existing ecological theory to highlight complex ecological relationships, such as *indirect effects,* that result in a high potential for unanticipated outcomes. Indirect effects are ecological interactions—mediated by consumers, competitors, disease, or other factors—that can change how one ecosystem component responds to natural or anthropogenic environmental change (e.g., Louda 1988, Carpenter et al. 1993, Zedler 1993). For example, if toxic contaminants eliminate the herbivores that control epiphytes, eelgrass may decline due to increased epiphyte loads, even if the contamination is within its tolerance range. Where such indirect effects are important, the tolerance of eelgrass to contamination would not be a good predictor of its distribution in contaminated habitats. Thus, priority should be given to research on ecological interactions that are likely to improve predictions about the response of the eelgrass-dominated ecosystem to external influences (Kingsolver et al. 1993).

Preliminary Results

Three preliminary results are suggested by an informal review of the data: First, there appears to be a bias toward bottom-up approaches, with less emphasis on the potential top-down effects of consumers (i.e., herbivores and carnivores) in structuring the eelgrass community. However, this trend may be changing, as evidenced by a recent study (Williams and Ruckelshaus 1993), in which both top-down and bottom-up effects were investigated. Because top-town processes have been shown to have very strong effects in structuring other aquatic ecosystems (Power 1990, Carpenter et al. 1985), priority should be given to determining their significance in eelgrass-dominated systems.

Second, field experiments have rarely been conducted in eelgrass beds to test hypotheses generated by descriptive field studies and laboratory experiments. Although field experiments are logistically difficult, they have been critical in determining both the types and relative importance of ecological interactions in other soft-sediment systems (Woodin 1978, Jumars 1993), and should be encouraged in research on eelgrass systems.

Third, much of the recent research seems to have been driven by an interest in developing transplantation as a policy option for mitigating habitat destruction (*Disturbance* models, Table 2; Bulthuis, ch. 4). Studies that address off-site influences on habitat quality (e.g., non-point source nutrient or toxic pollution) (*Stress* models, Box 2), are relatively rare. This case illustrates how the particular ecological model adopted to explain eelgrass decline has significance both for management policy and future ecological research (Box 2). Research priority should be given to understanding the role of habitat quality in the persistence of natural eelgrass beds and in the success of mitigation projects.

Box 2

Alternative models for eelgrass decline

Habitat Destruction (Disturbance) Models

Problem Definition:	Habitat destruction, due to disturbance
Assessment/Monitoring:	Inventory habitat, status of populations
Corrective Action:	Mitigation (replacement or enhancement)
Research Priorities:	Identify biological and physical factors affecting transplant success

Light-Limitation (Stress) Model

Problem Definition:	Reduction in habitat quality due to turbidity
Assessment/Monitoring:	Monitor light attenuation, population "health"
Corrective Action	Manage water clarity
Research Priorities:	Identify factors affecting light levels, study effects of light on performance/distribution of eelgrass.

Conclusions

Our goal in developing the ZOSTERA database is to define a scientific research agenda that both advances fundamental ecological knowledge and simultaneously contributes to solving environmental problems. Analysis of the ZOSTERA database will identify new research directions, based on previous research effort, research quality, and policy-relevant ecological complexity. Central to this effort will be the production of an "overlay" of management information needs generated by policy analysis (Hershman and Lind, ch. 8), permitting decision-makers to identify research programs that both answer important ecological questions and address the information needs of environmental managers.

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Appendix: ZOSTERA Database

The ZOSTERA database is a relational database, using RBASE software, that consists of four linked "tables" or files:

1. The PUBLICATION table contains bibliographic information, identifying the source of data. This is the master file that links all the other files in the database.

2. The FUNDING table contains records describing the sources of support for the study, based on the sponsoring agency(ies) or citations in the "Acknowledgments" of the publication. More than one FUNDING record may be associated with a given PUBLICATION record.

3. Each record in the STUDY table is based on a set of sampling or experimental units. That is, the observations taken on a set of plots in the field or plants taken into the lab would make up a "study." Because several studies may be reported in a single publication, more than one STUDY record may be associated with a given PUBLICATION record. Information about a given study would include
   - Location
   - Approach: Experimental vs. observational
   - Context: Lab, field, mesocosm, microcosm
   - "Quality": Design, replication, duration and frequency of sampling

4. The MODEL table records the specific models that were tested in a given study. Thus, each MODEL record documents the relationship between a single pair of independent and dependent variables. Because several models may be tested in a particular study, more than one MODEL record may be associated with a given STUDY record. For example, investigators may have measured how several plant characteristics (such as leaf length and width, nutrient content, and growth rate) respond to various fertilization treatments. Information recorded about a given model includes
   - Class of model: one of six classes (see Box 1)
   - Dependent and independent variables
   - Relationship between dependent and independent variables (e.g. statistical significance, sign of the relationship, whether other variables were simultaneously manipulated or measured).

CONCLUDING REMARKS

During the seminar and subsequent meetings of the Interdisciplinary Seagrass Working Group, several key issues emerged. These issues have direct bearing on future coastal zone management in the Pacific Northwest and include

- **The potential for non-point source impacts on the quantity and quality of habitat suitable for persistence of seagrasses.** Light limitation of seagrass distribution has been documented for numerous other seagrass systems and is currently under investigation in Puget Sound. However, the need for new policy directed at managing the effects of dredging, agriculture, forestry, urbanization or other human activities on seagrass resources cannot be assessed without further scientific studies that document the nature and extent of impacts from these activities to seagrass habitat quality.

- **The need for resource inventories documenting seagrass distributions and characterizing populations.** Avoidance and minimization of impacts depends on an adequate under standing of the extent and condition of native seagrass populations. Basin-scale planning and restoration-siting also depend on accurate information about historic and present seagrass distribution. In our region, this information is almost entirely lacking, particularly for subtidal populations. Defining the scale and resolution of a comprehensive baseline inventory is an urgent policy and research priority. The distribution and spread of exotic seagrasses, along with possible possible impacts to native ecosystems, also requires further study.

- **The need for restoration of seagrass systems destroyed by coastal zone development.** Despite our lack of knowledge about historical distributions, unavoidable impacts on extant seagrass populations occur and require mitigation. In our region, seagrass transplant technology has not been successful at the spatial scales necessary to comply with a "no net loss" mitigation goal. Research on habitat suitability, transplant techniques and source population characteristics is needed to improve success of mitigation efforts. Policy directed toward monitoring and evaluation of mitigation attempts is also needed to enhance institutional learning.

- **Enhanced coordination of regulatory and management activities.** Attention to seagrasses by regulators and managers occurs mostly through the review of development projects. In these cases, seagrass impacts are one of many impacts reviewed using general criteria. There is no specific seagrass policy in the Pacific Northwest although Washington Department of Fisheries is developing one (Fresh, ch. 6). Missing also are specific seagrass management programs that can monitor and protect the resources from threats not associated with development projects (e.g. boating, invasive species and cumulative impacts).

- **Ethnobotanical information and its relevance to policy decisions.** Ethnobotanical investigations briefly described in Wyllie-Echeverria and Phillips (ch. 1) raise several questions: 1) Is this type of information useful for regional seagrass management or is it simply of academic interest? 2) Are seagrasses, in addition to being an important component in coastal food webs, also an important cultural resource? and should plans to designate "Marine Protected Areas" incorporate this type of information? and 3) Are there medical and nutritional properties to the plants that warrant further examination? These questions might provide the basis for future analysis.

- **Comparative studies with seagrass systems and policy agendas and activities in other regions of the U.S.** During the formulation of the seminar we realized the importance of evaluating scientific and institutional models derived from Atlantic and Gulf regions regarding their appropriateness for the Pacific Northwest. Before we can determine whether Pacific Northwest seagrass systems and management histories are uniquely different and warrant special attention these comparisons are necessary.

- **The need for linking management research with basic ecological research.** We propose that this research could take the form of an "experiment station". This approach would allow us to simulate cultural activities that create or destroy seagrass habitats. Much of the current scientific research is driven by the regulatory environment. This environment builds a case for preservation and establishes strict standards for transplants, based on "no net loss" criteria. A research environment is needed that allows for more bold work not burdened by this bias toward regulatory approaches.

Additionally, we propose that this type of analysis should extend to other submerged land habitats. In the Pacific Northwest, "submerged lands", as compared to "shorelands", have received little attention from both research scientists and coastal zone managers. Seagrass management should be folded into this larger scheme of management. Comparative research on management forms and operations in other states, regarding "submerged land management", and the place of seagrasses within this management, needs to be done before specific recommendations regarding Pacific Northwest seagrass management can be made.

In summary, we realize that, while this is not the beginning of discussions involving seagrass science and policy, it is also not the end. Our immediate goal is to design the possible forms the next iteration should take. Toward that end, we introduced two corresponding yet interdependent approaches to defining priorities for policy development and ecological research regarding seagrasses in the Pacific Northwest region (Hershman and Lind ch. 8; Olson and Straub, ch. 9). Ultimately, this discussion will, and should, involve a wider audience. This document provides a "white paper" around which future discussion can be focused.